Betelgeuse
ASTRONOMY

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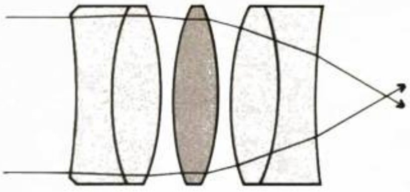
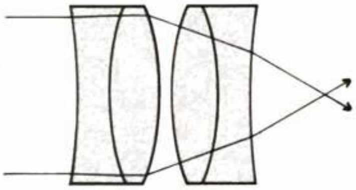
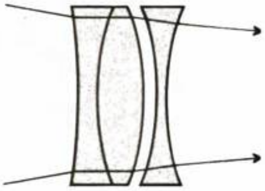
Series 4000 Barlow Lenses: The most sophisticated Barlows ever developed for commercial telescopes, these 2X and 2.8X Telenegative Amplifiers include 3-element, air-spaced, multi-coated optics, unmatched in image resolution and color correction. Both models optically complement the Series 4000 eyepieces, while significantly enhancing the performance of other eyepieces as well.



Meade 5-element Super Plössl design: the central lens element enables significant reductions in chromatic aberration and edge-distortions over other premium Plössl designs.



Other premium Plössls: include only the traditional 4-elements.



Meade Series 4000 Barlows: 3 elements, air-spaced, instead of the standard 2 non-air-spaced elements.

Series 4000 Eyepieces and Barlows

Super Plössls (5-elements)	APPARENT FIELD	BARREL DIA.	PARFOCAL
6.4mm	52°	1¼"	Yes
9.7mm	52°	1¼"	Yes
12.4mm	52°	1¼"	Yes
15mm	52°	1¼"	Yes
20mm	52°	1¼"	Yes
26mm	52°	1¼"	Yes
32mm	52°	1¼"	Yes
40mm	44°	1¼"	No
56mm	52°	2"	No
Super Wide Angles (6-elements)			
13.8mm	67°	1¼"	Yes
18mm	67°	1¼"	Yes
24.5mm	67°	1¼"	Yes
32mm	67°	2"	No
40mm	67°	2"	No
Ultra Wide Angles (8-elements)			
4.7mm	84°	1¼"	Yes
6.7mm	84°	1¼"	Yes
8.8mm	84°	1¼" & 2"	Yes
14mm	84°	1¼" & 2"	No
Barlow Lenses (3-elements, air-spaced)			
#140 2X Telenegative Amplifier		1¼"	Yes
#142 2.8X Telenegative Amplifier		1¼"	Yes

Meade 2" Mirror Diagonal: For attachment to Schmidt-Cassegrain telescopes, the 2" Mirror Diagonal permits use of Series 4000 eyepieces with 2" barrels. The 1/10-wave-flat Pyrex mirror, manufactured at the Meade Costa Mesa optical facility, is multi-coated with enhanced aluminum for maximum reflectance. An adapter for 1¼" eyepieces is included.

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Prices: Notwithstanding their performance standards and optical sophistication, Meade Series 4000 eyepieces and Barlows are priced very competitively with other premium oculars and Barlows.

Warranty: All Series 4000 systems are covered by the Meade Limited Lifetime Warranty—the most extensive in the industry. See the Meade catalog for details.

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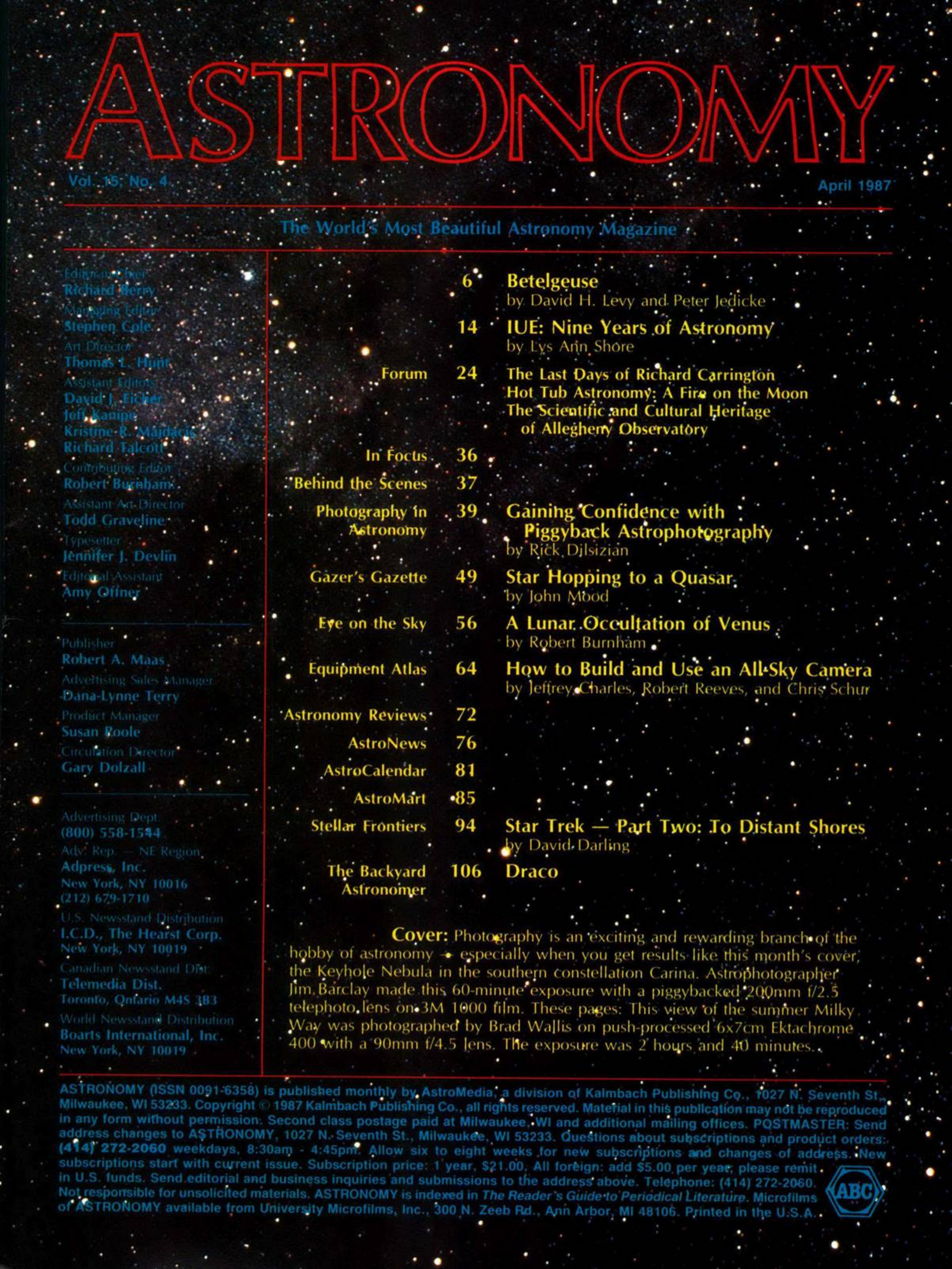

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Cover: Photography is an exciting and rewarding branch of the hobby of astronomy — especially when you get results like this month's cover, the Keyhole Nebula in the southern constellation Carina. Astrophotographer Jim Barclay made this 60-minute exposure with a piggybacked 200mm f/2.5 telephoto lens on 3M 1000 film. These pages: This view of the summer Milky Way was photographed by Brad Wallis on push-processed 6x7cm Ektachrome 400 with a 90mm f/4.5 lens. The exposure was 2 hours and 40 minutes.

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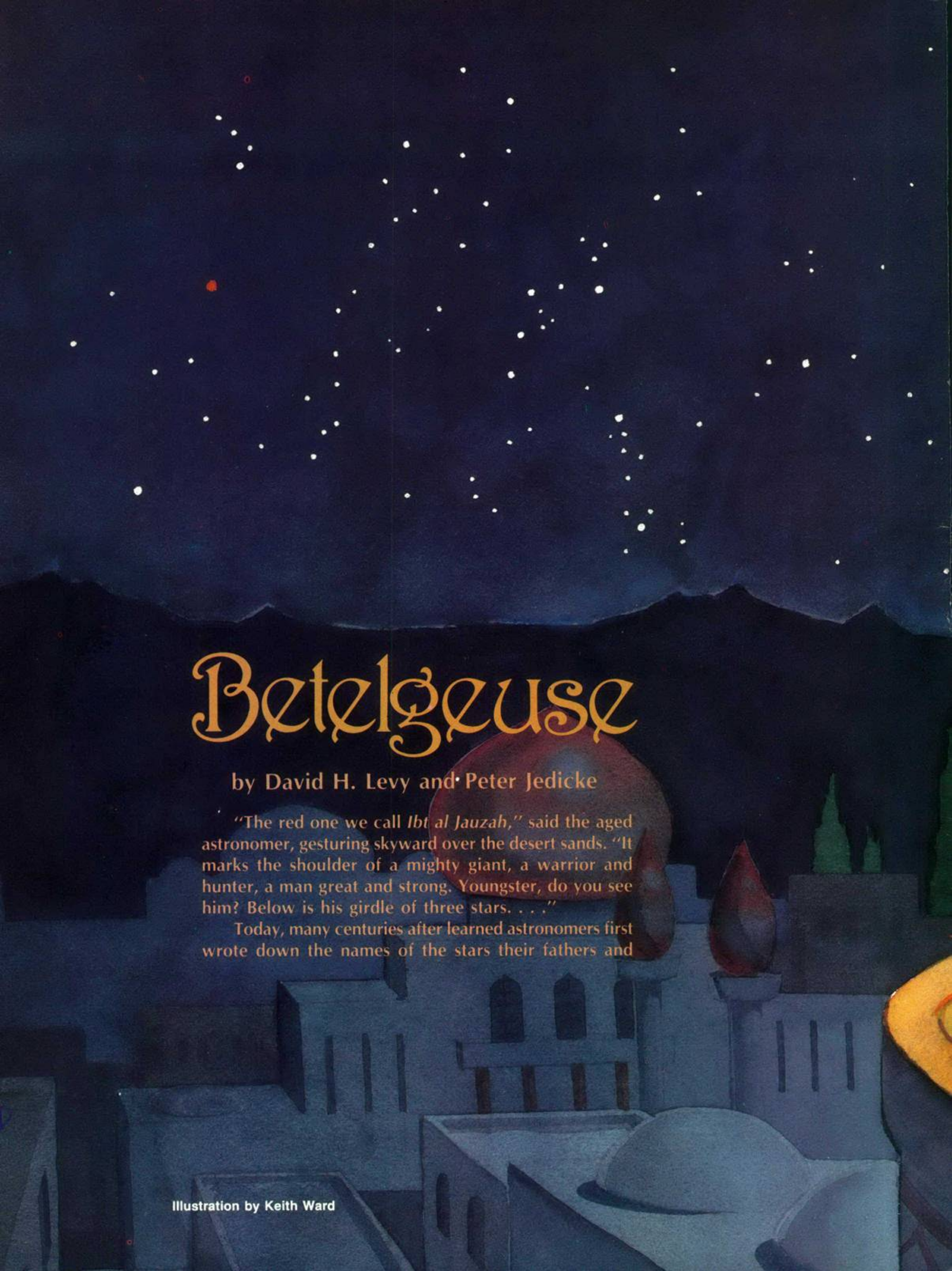


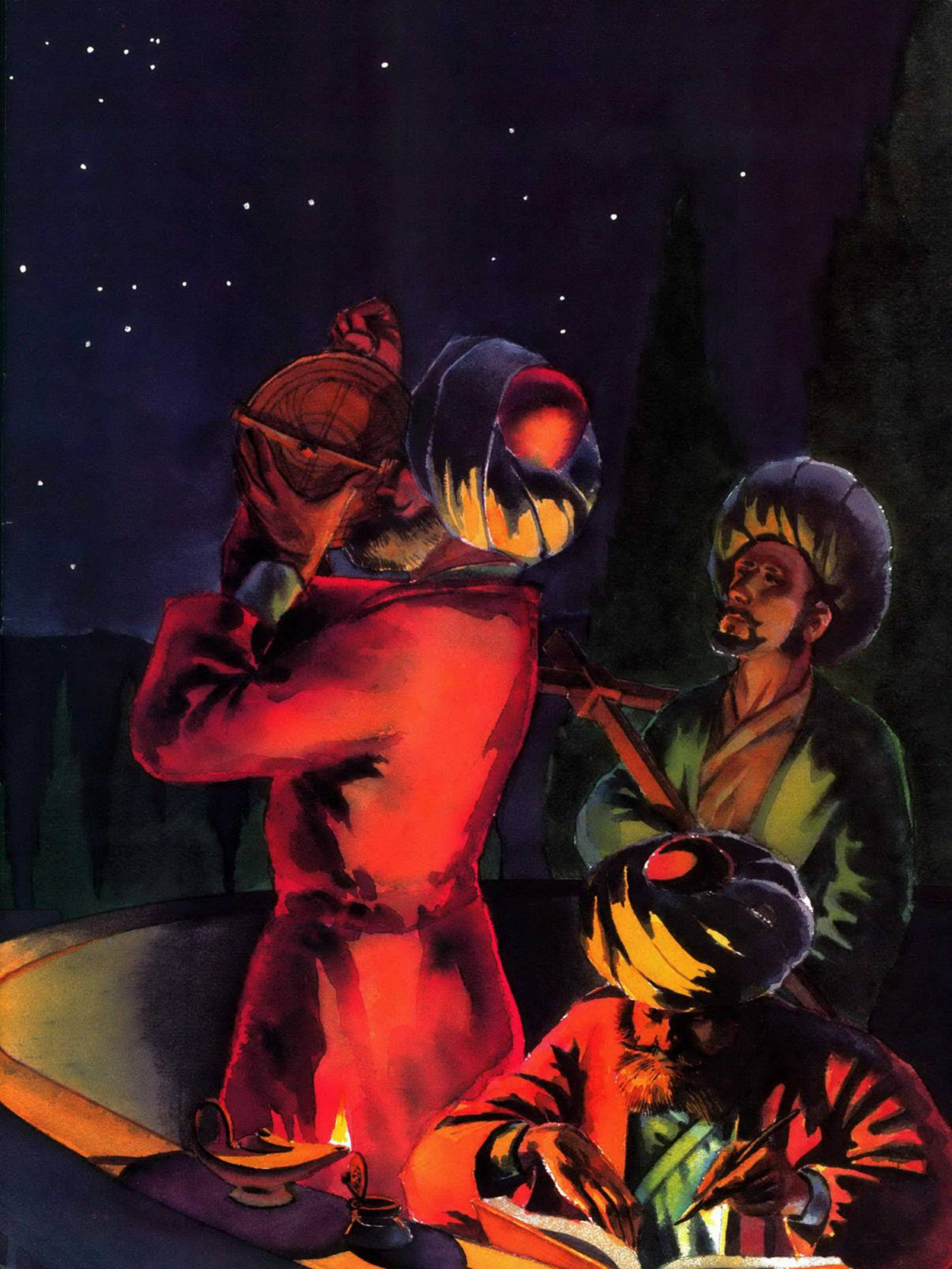
Betelgeuse

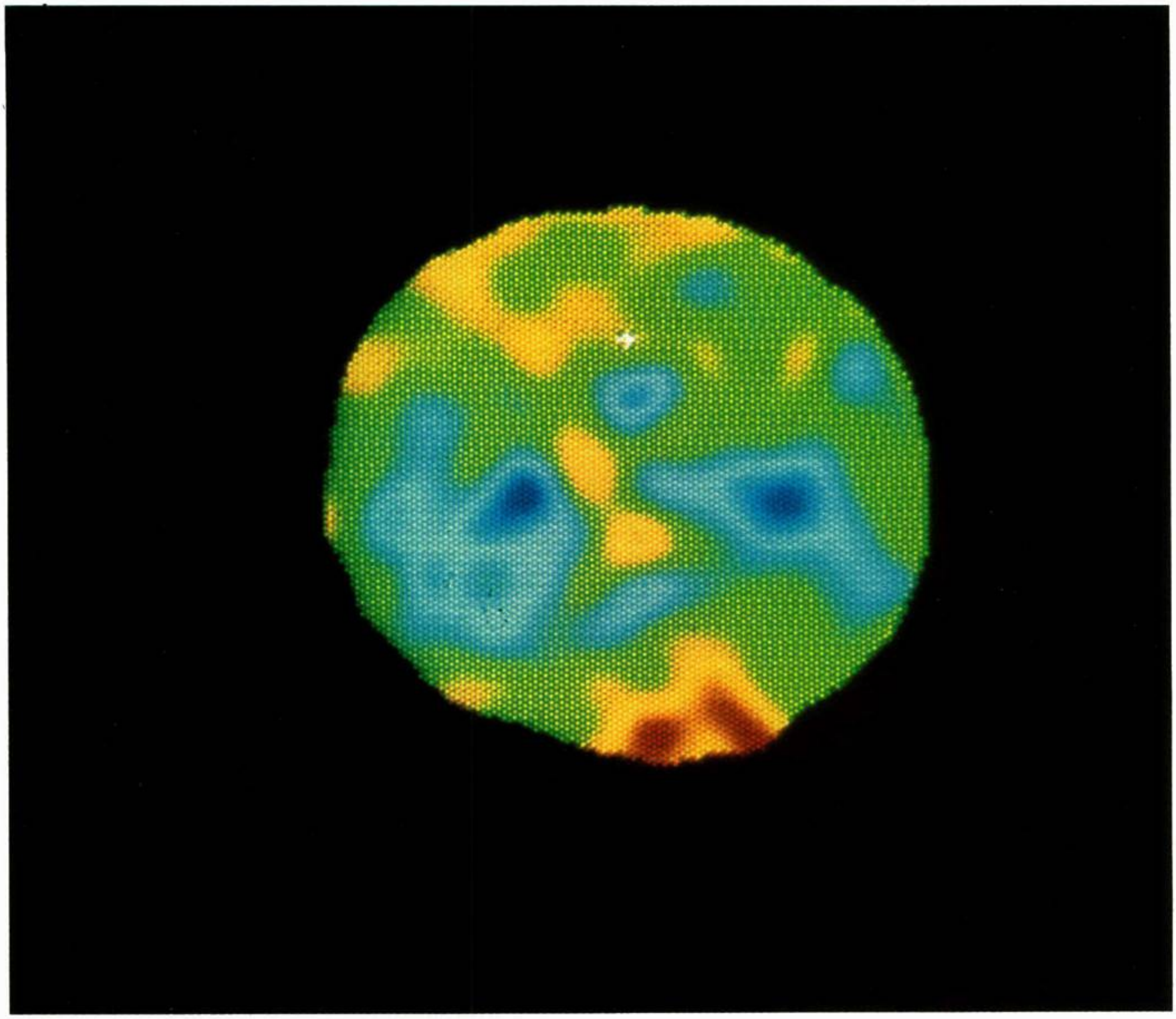
by David H. Levy and Peter Jedicke

"The red one we call *Ibt al Jauzah,*" said the aged astronomer, gesturing skyward over the desert sands. "It marks the shoulder of a mighty giant, a warrior and hunter, a man great and strong. Youngster, do you see him? Below is his girdle of three stars. . . ."

Today, many centuries after learned astronomers first wrote down the names of the stars their fathers and

Illustration by Keith Ward





After taking hundreds of short exposures that "froze" atmospheric distortion, astronomers reconstructed a single sharp image of Betelgeuse from them. This technique, called speckle interferometry, revealed brightness variations on the disk of this supergiant star. Astronomers have more recently used speckle interferometry to measure the orbits of two close companion stars that orbit Betelgeuse. Photograph courtesy National Optical Astronomy Observatories.

grandfathers had spoken, we still introduce our children to "Beetle Juice," the ruddy star in the shoulder of Orion the Hunter. The star's name (correctly pronounced BET-el-jooz) is Arabic for "armpit of the Central One."

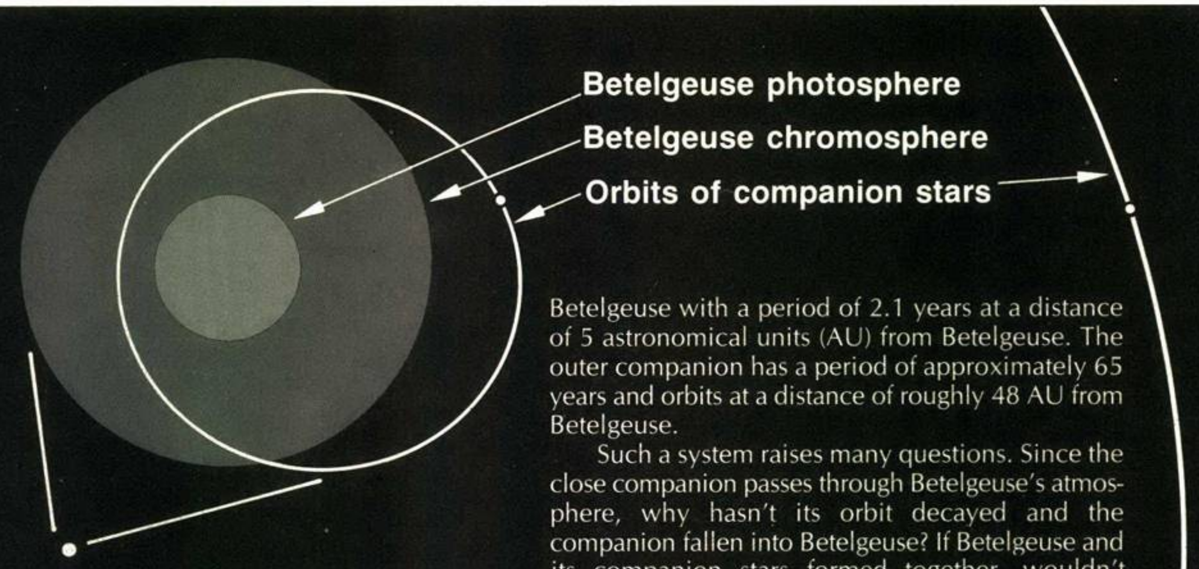
From city or country sky, from almost any part of the world, the majestic figure of Orion dominates the sky with belt, sword, and club. Ruddy Betelgeuse forms the left shoulder of the figure; it is the most conspicuous star in this conspicuous group of stars. Why ruddy? Betelgeuse is a cool star, so it glows with the orange light of a barbecue grill rather than with the harsh blue glare of a welder's arc.

A star's color tells astronomers which wavelength of light is most intense in the spectrum of the star's light. This in turn allows a straightforward calculation that yields the effective temperature of the star's surface. The light from Betelgeuse shows that the star has a temperature of just under 4,000 Kelvins — a cool star by astronomical standards. The Sun has a temperature of 5,800 Kelvins, and Rigel boasts a temperature of 35,000 Kelvins. (In comparison the average temperature of Earth's surface is 285 Kelvins.)

In the early 1900s astronomers classed hundreds of thousands of stars by their spectral types. Spectral types are related to star colors by temperature. If a star is cool, and therefore red, metal atoms in its atmosphere absorb certain characteristic wavelengths escaping into space. Betelgeuse is so cool, in fact, that we even see the characteristic lines of certain molecules — titanium oxide, for example. An astronomer can look at a spectrum and instantly recognize those particular lines.

In hotter stars different atoms absorb different wavelengths, so the spectrum also reveals the temperature of the star. Cool stars like Betelgeuse belong to type M. Type K stars are a bit hotter. Our Sun is the next step, a type G star, at about 6,000 Kelvins. The hottest stars are class O, at about 50,000 Kelvins.

In almost every case the figures we see in the sky are chance alignments of unrelated stars. The stars appear together because they happen to lie in the same general direction from Earth. There are, however, two notable exceptions. One is the Big Dipper, actually the remains



Betelgeuse a Triple Star?

Using speckle interferometry, three Harvard-Smithsonian astronomers have discovered that Betelgeuse has two close companion stars, the inner one so close it passes through Betelgeuse's tenuous outer atmosphere. The two companions are much fainter than Betelgeuse itself. The closer star orbits Betelgeuse with a period of 2.1 years at a distance of 5 astronomical units (AU) from Betelgeuse. The outer companion has a period of approximately 65 years and orbits at a distance of roughly 48 AU from Betelgeuse.

Such a system raises many questions. Since the close companion passes through Betelgeuse's atmosphere, why hasn't its orbit decayed and the companion fallen into Betelgeuse? If Betelgeuse and its companion stars formed together, wouldn't massive Betelgeuse have disrupted the less massive star before it finished forming? Perhaps what we're seeing is a pair of stars that have exchanged material and evolved together. Stars do not spend much of their lives as supergiants; it is possible Betelgeuse has become a supergiant so recently that the companion star's orbit simply hasn't had time to decay.

of a star cluster, and the other is Orion. Most of Orion's bright stars are young objects lying in a dense region of one of our Galaxy's spiral arms. Orion is a vast nursery of newborn stars, a place where gas condenses to make new stars, a place where stars only a few hundred thousand years old mingle with the hydrogen gas that gave birth to them. Most of the stars in Orion are blue because they are very young, very hot stars.

Betelgeuse is not part of the Orion group. The star is closer to us than most of the other stars in Orion, and it is a part of the constellation Orion only because it lies on the same line of sight.

How do we know this? Betelgeuse is close enough that, as Earth moves in its orbit around the Sun, we see Betelgeuse shift ever so slightly against a background of still more distant stars. For Betelgeuse this shift, called trigonometric parallax, is almost immeasurably small. The best astronomers can do, based on parallax measurements, is state that the star lies roughly more than 100 but less than 400 parsecs with a best value of about 200 parsecs, or 650 light-years from Earth. But the bright blue stars in Orion are around 1,500 parsecs away, making Betelgeuse a near neighbor in comparison.

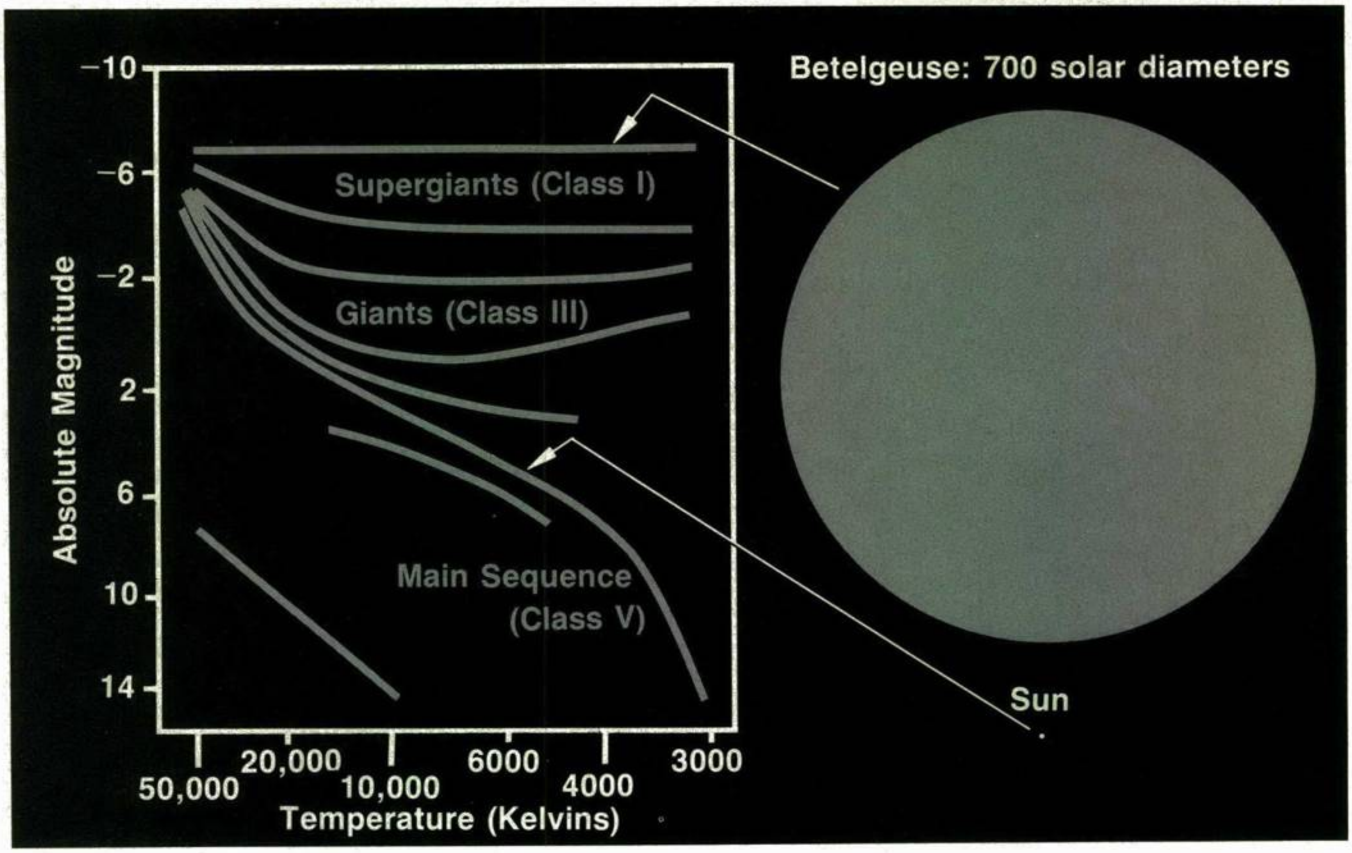
Two factors — real brightness and distance — determine how bright or faint a star appears to us. Look out your window some evening and study the "apparent" brightnesses of the streetlights in your neighborhood. If these lights are all of the same size and manufacture, they should each put out the same amount of light. But that's not how they look. The closest ones appear the brightest, so we say they have the greatest apparent brightness. This is an obvious fact, something we don't often consider consciously.

Now suppose we uprooted every light on your street and remounted each one at a distance of ten houses from you. All of them would then appear to be equally bright. What would happen, though, if you included lights from intersections and along the wide boulevards? These lights have higher wattage bulbs than your neighborhood lights. Although they are actually more luminous, they appear fainter than the one in front of your house because they are farther from your home. Were these brighter lights also moved to a standard distance ten houses away, they would then appear brighter than the smaller lights. An astronomer would say their "absolute magnitude" is greater.

So it is with stars. Sirius, the brightest star in the sky, appears close to Betelgeuse. But Sirius looks bright because it is a mere 2.5 parsecs (8 light-years) from the Sun — a cosmic stone's throw distant; Betelgeuse appears bright because it is far more luminous than Sirius.

When astronomers want to compare the true energy output of stars, they convert the apparent magnitude of each star — how bright the star *appears* — to its absolute magnitude. Absolute magnitude is nothing more than how bright a star *would* look if it were 10 parsecs (32 light-years) from the Sun. Knowing how bright Betelgeuse appears in our winter sky and having determined its distance by measuring its tiny trigonometric parallax, astronomers have calculated the absolute magnitude of Betelgeuse. The absolute magnitude of Betelgeuse, in round numbers, is −6, while that of the Sun is +4. This means Betelgeuse emits roughly 10,000 times as much light as our Sun does.

When we plot Betelgeuse on a graph with other stars according to surface temperature and absolute magnitude (a graph astronomers call the Hertzsprung-Russell [H-R] diagram), Betelgeuse's combination of cool temperature and extreme brightness places it far away from average stars. By plotting thousands of stars on such plots, astronomers have found that stars tend to fall into natural groupings. Near the top of the H-R diagram, where the intrinsically bright stars are plotted, we find a group astron-



omers call supergiants and label with the Roman numeral I. The supergiant branch seems to be split when it comes to very cool red stars. The upper sub-branch is known as Ia ("Bright Supergiants") and the lower as Ib ("Supergiants"). Betelgeuse lies midway between the two branches, so astrophysicists split the difference and class Betelgeuse as a "Iab" star.

Below the supergiants are several varieties of giant stars (classes II, III, and IV). Giants are less luminous and smaller than supergiants. Class V slopes diagonally across the H-R diagram; astronomers call the stars on the diagonal the Main Sequence, which contains normal, stable stars. At one end of the main sequence we find hot, bright blue stars like Achernar, the brightest star in Eridanus. At the other end are the small, faint red stars called red dwarfs. Stars such as the Sun lie in the middle: they are moderately hot, moderately sized, yellow-white stars.

The H-R diagram can also be used in reverse to find the distance to Betelgeuse. From Betelgeuse's spectrum astronomers can make a pretty good guess about the star's absolute magnitude. This "guesstimate" is used to find the distance to the star, since the apparent magnitude is already known. For Betelgeuse this method gives a distance of 95 parsecs, a result substantially different from trigonometric parallax. Uncertainties this large are not uncommon in astronomy.

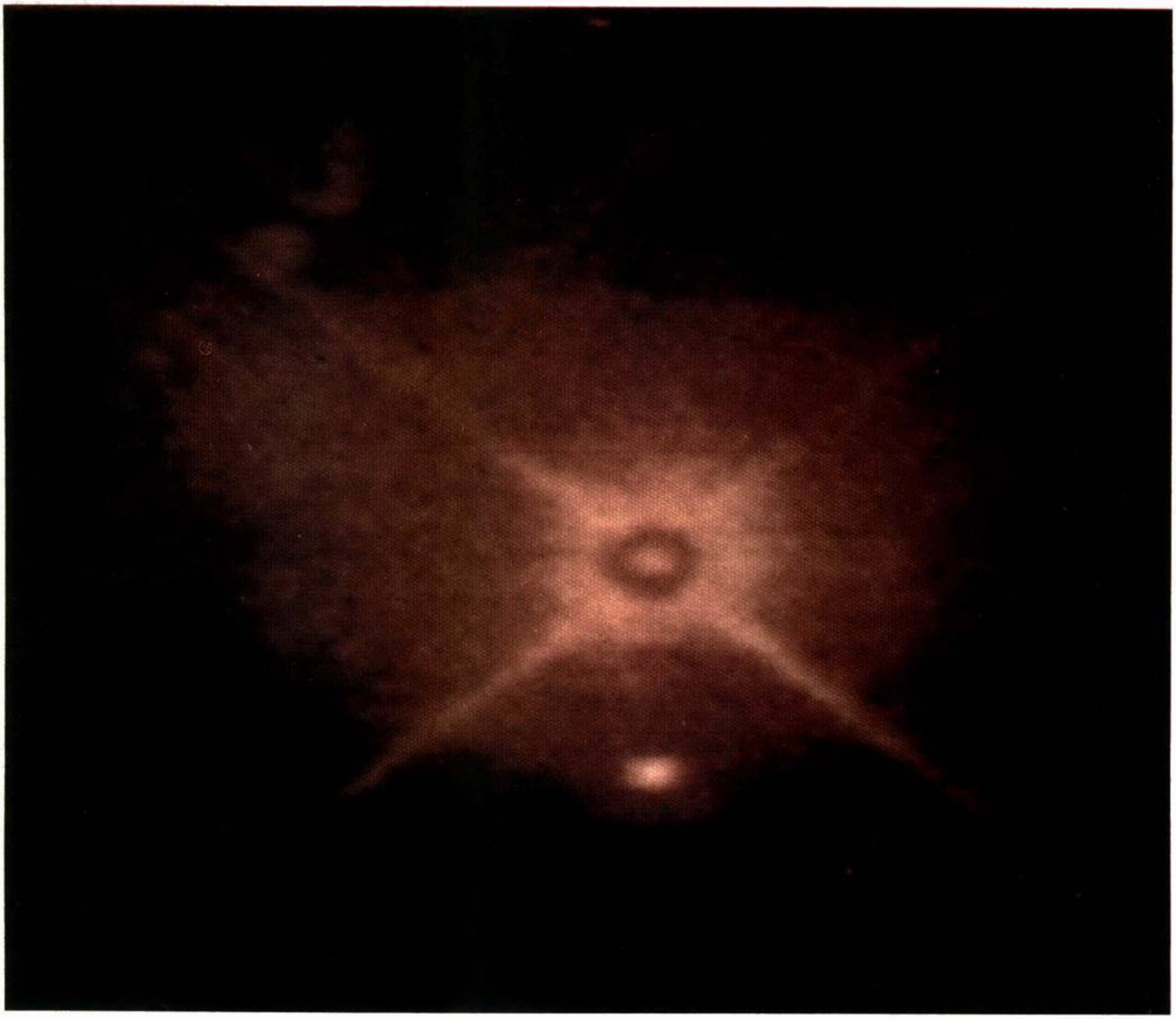
We have called Betelgeuse a supergiant star. How do astronomers know this? The story is somewhat roundabout, but it goes like this: the hotter an object is, the more light and energy each square inch of its surface gives off; the cooler an object is, the less light and energy each square inch gives off. In fact, the total energy emitted by a given area depends on the fourth power of the temperature according to the Stefan-Boltzmann law for radiating bodies. This means that a square inch of the surface of a blue supergiant pours forth thousands of times as much energy as an equal area on the surface of Betelgeuse.

If hot blue stars are so luminous, how can cool red Betelgeuse vie with their light output? The answer is simple: Betelgeuse is enormous. Although each square inch radiates less energy, Betelgeuse has many times more square inches than a blue supergiant has. Astrophysicists long ago realized, before they had any independent way to verify it, that the luminous red stars had to be supergiants in size. Blue stars on the main sequence may have the same absolute magnitude, but they are tiny in comparison.

Since Betelgeuse is the closest of the red supergiants, astronomers expected Betelgeuse to have an *angular* disk larger than that of any other star in the heavens except the Sun. Two astronomers at a California mountaintop observatory confirmed this prediction in a spectacular way.

The key was an unconventional observing technique. Using an interferometer attached to the 100-inch Hooker telescope on Mount Wilson, Albert Michelson and Francis Pease resolved the disk of Betelgeuse in 1920. They attached small, precise mirrors to the ends of a 50-foot-long boom extending across the aperture of the 100-inch telescope, the biggest telescope in the world at the time. When they pointed the telescope at Betelgeuse, the small mirrors directed the star's light through the instrument, and the light beams interacted as if the telescope had an aperture equal to the distance between the small mirrors, rather than 100 inches, and yielded much higher resolution than the telescope itself could ever provide.

The technique enabled the astronomers to observe interference fringes. As the mirrors were moved outward on the long boom, the visibility of the fringes changed enabling Michelson and Pease to calculate that the angular diameter of Betelgeuse lies between one-twentieth and one-thirtieth of a second of arc — a very small angle



Its gaseous halo revealed in the light of potassium atoms, Betelgeuse proves again the spendthrift. Betelgeuse is unable to hold the tenuous outer reaches of its gaseous envelope and has thrown a trillion-mile halo of its atmosphere into the space around itself. The halo is not made of potassium alone: the potassium atoms serve to trace the gas cloud. Betelgeuse also lies at the center of a vast cloud of material that has condensed into dust grains, probably carbon in the form of graphite. Photo courtesy of Los Alamos Scientific Laboratory EG&G, Inc.

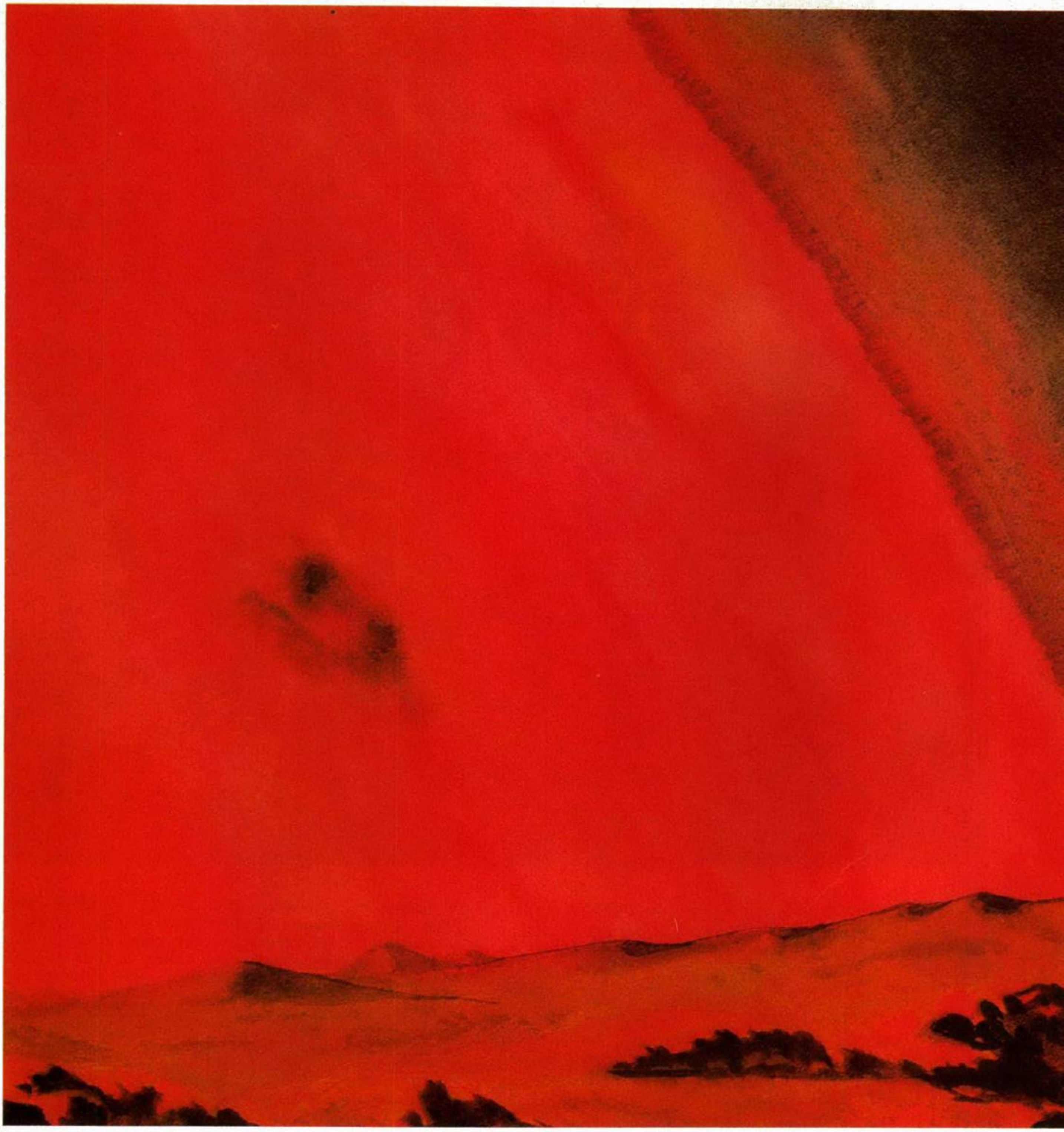
indeed. But this very tiny angle corresponds to an enormous size at the distance of Betelgeuse: a diameter of one-and-a-half billion kilometers.

But size brings with it a problem: the star's atmosphere is somewhat unstable. If you were to watch Betelgeuse closely for several years, you might notice its brightness changes. The first to notice this variation was John Herschel, a noted astronomer in his own right and the son of William Herschel, the discoverer of the planet Uranus. In 1836 John alerted other astronomers to Betelgeuse's "marked and striking" variations.

Betelgeuse belongs to the class of stars modern astronomers call semi-regular variables. It varies cyclically with a period of roughly 2,060 days (almost six years) and changes by about a magnitude. By itself this slow variation would make for boring observing. However, Betelgeuse also undergoes irregular variations you can detect from your backyard over a few weeks.

What's happening? Astronomers think the outer layers of the star expand slowly for several years and then shrink again, so the surface area alternately increases and decreases, and the temperature rises and falls, making the star brighten and dim. Red supergiants pulsate this way because their atmospheres are not quite stable. When the star is smallest, the atmosphere absorbs a bit too much of the energy passing through it, so the atmosphere heats and expands. As it expands, it becomes thinner. Energy then passes through the outer layers more easily so the gases cool, and the star shrinks again.

In addition to the slow cyclic variation, Betelgeuse shows a more rapid flickering. Over the course of a few weeks or months the star brightens quickly and then fades again somewhat more slowly. The variation is not entirely unexpected. Theoretical models of the interior and atmospheric structure of stars — models devised some years ago and refined since — had hinted that hot gases move up and down on a vast scale in a star like Betelgeuse. Photographs of our Sun's surface show rising pockets of hot gas bubbling up from underneath, but the bubbles, or granules, are typically a thousand kilometers across and appear and disappear in just a few minutes. Theory



predicts that for the Sun vertical motion extends to a depth of several tens of thousands of kilometers below the surface — a small fraction of the Sun's diameter. The same theory applied to Betelgeuse says convection extends all the way down to the outer edge of Betelgeuse's core, and the granules, dubbed supergranules, are a large fraction of the star's diameter.

In the mid-1970s astronomers at Kitt Peak National Observatory decided to try a sophisticated imaging technique called speckle interferometry with Betelgeuse. By taking pictures of the visible disk, they hoped to see supergranules on the star's bloated disk. Although the details in the resulting speckle images are not very clear, they do reveal large dark areas that some astronomers believe are really supergranules on the surface.

Convection has serious implications for the process of nuclear fusion, the energy source of stars. One reason a star like our Sun is reasonably stable over billions of years is that nuclear fusion takes place at the slowly expanding outer surface of the core. With little or no stirring of the material in and around the core the fusion region placidly eats its way outward from the center of the Sun.

In Betelgeuse, however, that orderliness is perturbed. Convection currents dredge up the products of nuclear fusion, such as the isotope carbon-13, and carry them into

The swollen disk of Betelgeuse looms above the scorched remnant of a small planet. Seven hundred times bigger and ten magnitudes more brilliant than our Sun, this supergiant star began life as a hot, luminous, blue star of 15 solar masses. The star rapidly burnt its fuel and evolved to its supergiant status in just a few tens of millions of years. Painting by Keith Ward.

the atmosphere. Deep convection disrupts the stability of a star's core by mixing in material that readily undergoes fusion in the high heat of the core. Astronomers do not understand all the things happening deep inside this star, but it is evident that Betelgeuse is undergoing evolutionary changes at a much faster pace than a star like the Sun.

Convection is also at work above the bright surface of Betelgeuse. As long ago as 1939 astronomers realized the gas in the atmosphere of Betelgeuse was moving outward at 15 kilometers per second or more because spectra showed certain spectral lines were blue-shifted. Significant quantities of gas had already escaped to form a spherical envelope or shell around the star.

The first direct evidence of such circumstellar shells around supergiants came not from Betelgeuse, but from observations of the double star Alpha Herculis. One star in this binary system is a red supergiant, while the other is a main-sequence star similar to the Sun. In 1956 Armand Deutsch determined that light from the main-sequence star was partially absorbed by matter surrounding the supergiant. The two stars are separated by 4.7 seconds of arc, which indicates that the shell around the supergiant extends at least 100 billion kilometers out from the supergiant.

Because it does not have a bright companion star to help astronomers detect its circumstellar shell, Betelgeuse had to wait. Evidence was finally found in 1975 by two astronomers at McDonald Observatory. Aiming the telescope slightly away from the brilliant glare of Betelgeuse, they detected the faint glow from potassium atoms in a circumstellar shell. Confirming observations made a few years later show that the outer edge of the envelope around Betelgeuse extends well over a trillion kilometers from Betelgeuse — so light from the star takes a good two months to escape the gas shell.

In the outer reaches of this vast globe the density of the potassium atoms that were observed is exceedingly low: each individual atom is the lone occupant of a volume the size of a household refrigerator. This may not seem like much, but there are about a million trillion trillion (10^{30}) such imaginary, almost-empty refrigerator-volumes in the gas shell.

Using the Doppler shift of spectral lines in the gas shell, astronomers have measured the speed at which atoms at various depths in this vast gas shell are traveling. Surprisingly, there is one layer that does not seem to be expanding, but beyond this layer the outward movement resumes. Astronomers estimate that Betelgeuse currently expels the equivalent of the Sun's mass in a few million years.

What will become of Betelgeuse in the next few million years is not at all clear. If it loses its outer envelope rapidly, the exposed core will cool and become a white dwarf. If the outer layers remain in place though, nuclear fusion will continue, and the already dense core will grow denser and hotter, perhaps blowing off its outer layers as a planetary nebula or ending in a cataclysmic explosion as a supernova.

For the time being, the bright ruddy star in Orion's shoulder still hides its secrets from us. There is much we do not know. But one thing you can count on: astronomers will continue to study Betelgeuse in the hope of learning more of its secrets.

David H. Levy is an observer with the International Halley Watch, the discoverer of two comets, and the author of many astronomy articles. Watch for his forthcoming book on observing variable stars, to be published by Cambridge University Press. Peter Jedicke is an enthusiastic amateur astronomer and teaches math and physics at Fanshaw College in London, Ontario. Jedicke was instrumental in getting the Canadian "telescope tariff" removed, to the benefit of Canada's amateur astronomers.

NINE YEARS OF

Like a promising student who blossoms into a Nobel Prize winner, the International Ultraviolet Explorer (IUE) satellite has dramatically surpassed the expectations of its creators. Designed to last three years, the orbiting observatory is now in its tenth year of operation, which makes it the longest-lived of all astronomical satellites. And, as high performance always creates higher demands, astronomers now hope IUE will last for another six or seven years.

Yoji Kondo, NASA project scientist for IUE, calls the satellite "the most productive telescope devised by humans." Lest this should sound like empty rhetoric, he hastens to back up his statement with a statistic: from IUE's launch in January 1978 until December 1985, a total of 1,136 scientific papers based on IUE data were published in scientific journals. These papers announced, explained, refined, and extended major discoveries in many areas of astronomy, from solar system to stellar to extragalactic research. "This satellite has been a monumental success," says Blair Savage of the University of Wisconsin at Madison, who with his colleague Klaas De Boer discovered the existence of the galactic halo using IUE.

To anyone familiar with the size of today's ground-based telescopes, IUE seems a rather insignificant instrument — a mere 45-centimeter (17.7-inch) f/15 Cassegrain telescope — to explore the universe with. But IUE's lofty position confers advantages. As Sumner Starrfield of Arizona State University at Tempe puts it: "At least we don't have to worry about clouds, although we do worry about occultations and radiation belts."

IUE orbits Earth in an elliptical geosynchronous orbit, which means it has a period equal to Earth's period of rotation but an orbital velocity that is not constant. This orbit is high enough that only about 17° of IUE's sky is occulted by the Earth. The path of the orbit permits twenty-four-hour contact with the NASA tracking station at Wallops Island, Virginia, as well as about ten hours a day of contact with the European Space Agency (ESA) control center in Villafranca del Castillo near Madrid, Spain.

By agreement NASA and ESA share the use of IUE, although NASA retains prime responsibility for the maintenance of the satellite. NASA controls the satellite for two eight-hour shifts each day and then passes the third eight-hour shift to ESA's control for the use of European guest observers.

IUE is not the first satellite to explore the universe at ultraviolet wavelengths — it was preceded by two Orbiting Astronomical Observatories sensitive to ultraviolet light, which cannot penetrate Earth's atmosphere — but IUE has certainly given us our clearest view yet of this region of the electromagnetic spectrum. Characterized by a shorter wavelength and greater energy, ultraviolet radiation carries information about more energetic astrophysical processes than visible light does. The information allows astronomers to gain a broader perspective on energetic phenomena than they could using ground-based observatories alone.

Robert Wilson of University College, London, who is the IUE project director for the British Science and Engineering Research Council (SERC), was a member of the team that created the original design for IUE. He admits, "I never thought it would last ten years, as it may easily do, even though I'm an optimist. The design lifetime was three years, and one year was standard at that time."

For a few days in August 1985, however, it looked as though the success story might come to an abrupt end: one of the three gyros used to point the satellite failed suddenly on August 17, leaving the spacecraft with only two working gyros. Three gyros are usually considered the minimum necessary to point a spacecraft's telescope. Of IUE's original six, one never functioned and two others had failed previously. The IUE staff at Goddard Space Flight Center in Greenbelt, Maryland, had, however, fashioned a two-gyro control system in anticipation of this inevitable event: within a few weeks the satellite was operating normally. The event spurred the staff to begin developing a one-gyro control system to be held in readiness if one of the remaining gyros fails. And it seems that a zero-gyro control system isn't beyond the bounds of reality.

Perhaps moved by an awareness of the satellite's mortality, however, the astronomical community has taken time to assess the scientific achievements of IUE's first eight years. Last July two hundred astronomers attended the first international symposium on IUE, which was held in London under the joint sponsorship of NASA, ESA, and SERC. Under the theme "New Insights in Astrophysics: Eight Years of UV Astronomy with IUE," the conference featured review talks in the areas of research that have been most profoundly affected by this long-lived satellite: comets, the solar system, cool stars, hot stars, interacting binaries, cataclysmic variables, the interstellar medium, galactic haloes, and active galaxies.

Longevity and Scientific Return

The unexpected longevity of IUE has greatly increased the value of its scientific contribution, in part by compiling a long baseline of observations that makes it possible to place short-term observations in context. For example, solar system astronomers like Paul Feldman of Johns Hopkins University in Baltimore, Maryland, would like to know if Jovian weather was normal during the Voyager flybys of Jupiter. Long-term observations from the IUE spacecraft suggest that indeed the weather was normal.

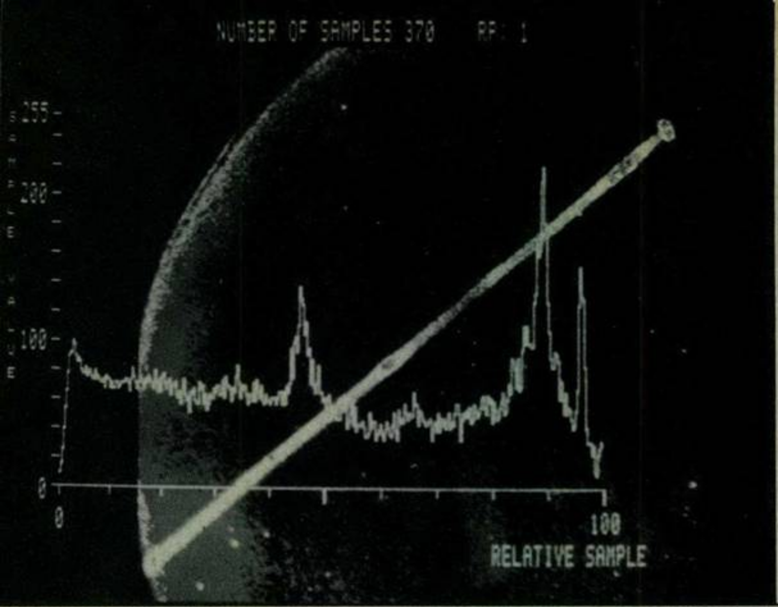
Thanks to careful calibration of IUE's instruments, the satellite's observations have been uniform. This uniformity provides consistent data that makes possible the detection of long-term variability, such as the star-spot cycle in RS Canum Venaticorum stars. And, Kondo points out, IUE's long lifetime permits complete observations. "With a short-lived satellite you may discover something new — but then your satellite's gone."

IUE has, for example, been able to observe the variability of active galactic nuclei in Type I Seyfert

Illustration by John Luttropp

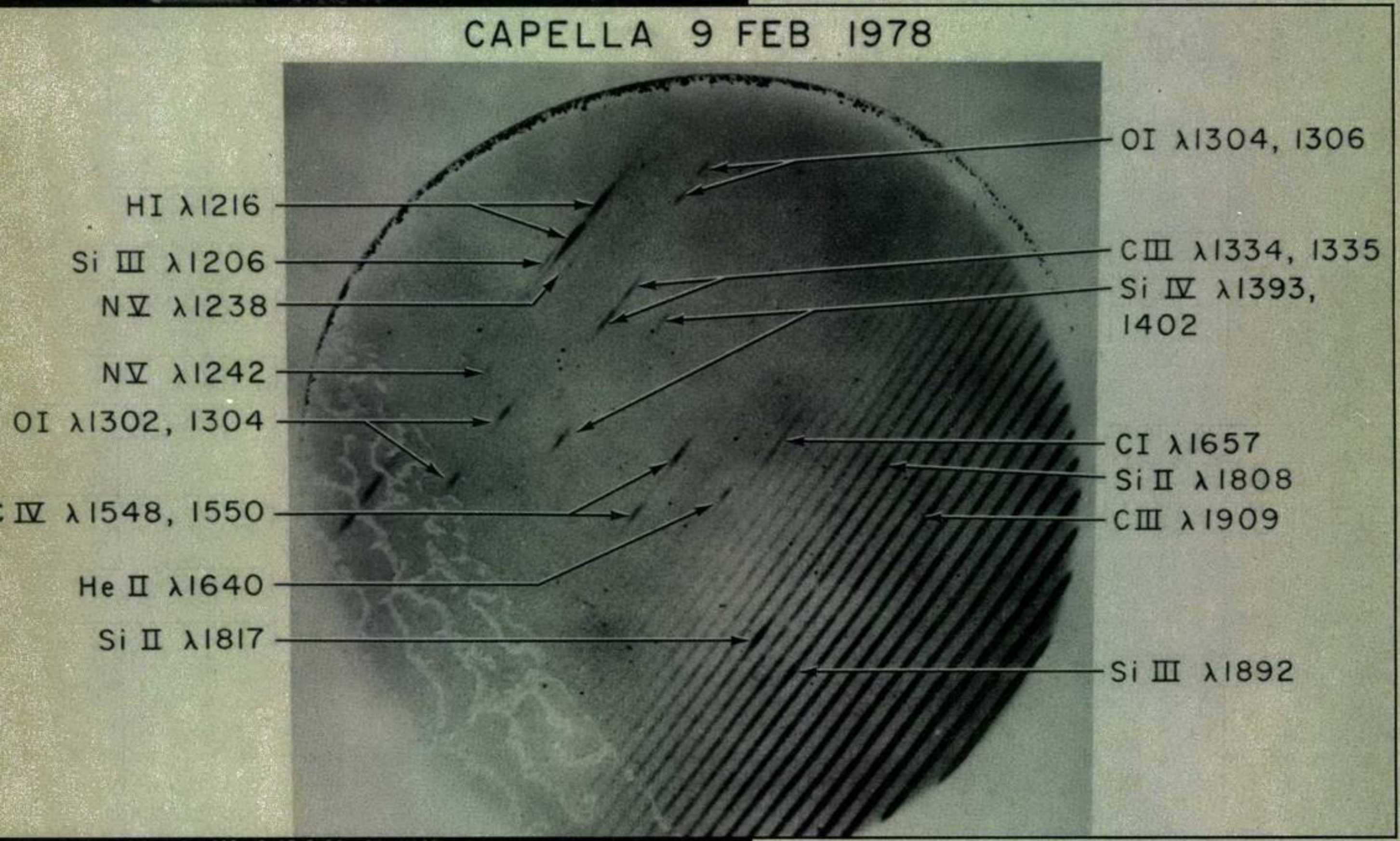
ASTRONOMY

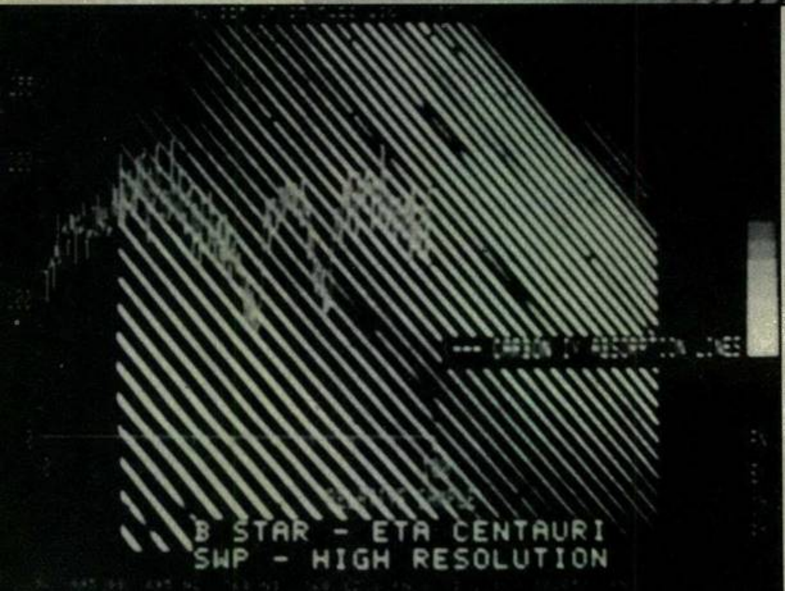
BY LYS ANN SHORE



Left and bottom left: The IUE satellite can take ultraviolet spectra in any of several modes. At left is a low-dispersion, short-wavelength image of the low-redshift Type I Seyfert galaxy, Fairall 9. Visible as bright spots are the Lyman-alpha emission lines of hydrogen (right) and the Carbon IV emission lines (center). At bottom is a high dispersion, short-wavelength spectrum of the Be star Eta Centauri, showing Carbon IV absorption lines (dark spots) at center. Superimposed on both spectra are quick-look scans of the same image. Both images courtesy Y. Kondo.

Below: The first spectrum ever obtained with IUE was this high-dispersion image of Capella. Emission lines show black and the important lines are indicated. The wavelength increases along each order from lower left to upper right (note that lines near the end of one order also show up at the beginning of the next order) and from upper left to lower right overall. Image courtesy J. L. Linsky.


CAPELLA 9 FEB 1978
OI λ1304, 1306
HI λ1216
Si III λ1206
N V λ1238
C III λ1334, 1335
Si IV λ1393, 1402
N V λ1242
OI λ1302, 1304
C I λ1657
Si II λ1808
IV λ1548, 1550
C III λ1909
He II λ1640
Si II λ1817
Si III λ1892


CARBON IV ABSORPTION LINES
B STAR - ETA CENTAURI
SWP - HIGH RESOLUTION

galaxies and BL Lacertae objects. The active galaxies observed with IUE are low-redshift objects, closer to Earth and intrinsically fainter than those that have ultraviolet lines observable from the ground. Marie-Helene Ulrich of the European Southern Observatory in Garching, West Germany, points out that IUE is an excellent tool for observing this type of variability because IUE offers "repeatability of observing conditions and constancy of the instrumental setup." Observations of NGC-4151, a Type I Seyfert galaxy that has been extensively studied at both ultraviolet and x-ray wavelengths, showed that in 1981 the galaxy changed from a normal Type I Seyfert with a small, extremely bright nucleus to a less luminous Type II Seyfert that has bright episodes.

Creative Observing

IUE's instrumentation has been the source of as much

REAL-TIME OBSERVING WITH IUE

It's late at night at Goddard Space Flight Center in Greenbelt, Maryland, and as a guest observer you've been scheduled for the "US 2" shift, which begins in one hour. You prepare the "scripts" that specify your observing sequence and then spend some time talking with staff members — a telescope operator and one of IUE's resident astronomers (RAs). Operators are technicians who hold bachelor's or master's degrees; RAs hold doctorates in astronomy and are rare birds who are, in the words of one of them, "scientists willing to fill what's essentially a support position, spending most of their time helping others to observe rather than doing their own observations." Having the telescope operator and RA in charge of operations allows you to concentrate on your own observing program, which is just now beginning.

The operator slews the telescope to your first target — a hot star. A low-resolution image of the starfield is displayed on your console. You identify the target star, the operator centers it in the large aperture of the spectrograph, and you begin the first exposure in high-dispersion mode. It's a bright target, so an exposure of a few minutes will yield a good image.

On the satellite the detector begins integrating the spectrum. Once the exposure is completed, the spectrum can be stored indefinitely in the detector. More likely, however, you're a typical guest observer who wants to see the data right away. So the telescope operator initiates a "read" — a systematic raster scan across the detector surface that covers half a million data points. The data passes through an analog-to-digital converter, where each data point is converted into a digit between 1 and 255.

The "read" takes about five minutes, after which the data is sent by radio signal to the NASA tracking station at Wallops Island on the northern part of Virginia's Chesapeake Bay peninsula. If you're unlucky, IUE might experience an "antenna null," when none of the satellite's four transmitting antennas is in a good orientation to Earth. If this is the case, Wallops Island might receive only bits and pieces of your spectrum, and the data would be lost because the transmission is a "destructive read." But this rarely happens.

Ordinarily your data is received safely at Wallops Island and immediately retransmitted the two hundred miles to Goddard via a communications satellite. Traveling along with the scientific data is information about the spacecraft itself. Some of this information, like the camera temperature, will be used in processing your data, while information on the status of the spacecraft is monitored by staff members responsible for the satellite's health.

Once this information is stripped off, the two-dimensional image of the spectrum is reconstructed pixel by pixel. This is then written to tape in a process called "archiving," which makes a permanent record of the exposure. The next stop is the observer's console, where you're seated, anxiously awaiting the results. You immediately perform a quick-look analysis: measuring the exposure level and checking the spectrum.

To conduct a thorough analysis, however, you need to have the spectrum extracted from the raw image and converted into a format that relates directly to the actual flux emitted by the star. Called "image processing," this task involves five basic steps:

1. The image is corrected for the geometric distortion of the camera.
2. Each of the half-million pixels is photometrically corrected to account for the sensitivity variation across the detector.
3. The wavelength calibration of the spectrum locates the spectrum with respect to the reseau — a geometric pattern permanently marked on the face of the camera — using calibration exposures of a lamp aboard the satellite.
4. The spectrum is extracted from the background to provide an image that has an intensity directly related to the amount of light falling on the detector.
5. If you had been in low-dispersion mode instead, an absolute flux calibration would be applied. (This can't be done for high-dispersion images because of the additional uncertainties introduced by the use of an extra grating, the cross-dispersing element, on the spectrograph.)

If you're lucky, your spectrum won't show much noise from background radiation, which is caused by charged particles in the Van Allen radiation belts that encircle Earth. If it does, you'll want to take shorter exposures next time. To complete the data analysis, you may decide to use one of the two Regional Data Analysis Facilities set up by NASA at Goddard and in Boulder, Colorado.

Meanwhile, the rest of your eight-hour shift lies ahead of you. You begin your next exposure, get up, stretch, and grab a quick cup of coffee. It's going to be a long night, but if you're lucky it could also be an exciting one.

— *Lys Ann Shore*

NASA Photo

joyful surprise as its longevity has. IUE features two spectrographs for ultraviolet spectroscopy, each of which can be used in high- or low-dispersion mode. One spectrograph is designed for the near ultraviolet (1900-3200 Angstroms) wavelength region and the other for the far ultraviolet (1150-1950 Angstroms). When IUE was launched, its designers believed its two vidicon detectors would be capable of only 15- to 20-minute exposures. In fact, single exposures of over 15 *hours* have been made successfully. If the 15-minute limit had held, says Savage, "many of the extragalactic interstellar-medium studies wouldn't have been possible."

Research on cool stars has necessitated even longer exposure times. Linsky and his group hold the record — a 24-hour exposure of Arcturus, a very faint star in the ultraviolet even though it's a zero-magnitude star in the visible. To make this marathon exposure, Linsky and his collaborators integrated for 12 hours over two shifts, waited out one shift, then continued the exposure for 12 more hours.

This type of creativity is one of the most distinctive features of the IUE project. Quite simply, IUE has proved capable of handling observations it was never designed for and that had not even been conceived of at the time of mission planning. This creativity has been especially important for solar system research because, as Feldman explains, "IUE was not designed to be user-friendly to the solar system observer." Solar system objects are moving targets, and observers can't guide the spacecraft's telescope continually the way they could guide a ground-based telescope.

Feldman's important IUE observations of the Io torus, the donut-shaped region of ionized gas that surrounds Jupiter along the orbit of Io, involved both long exposure times (10 to 15 hours) and complex maneuvers of the spacecraft. "The torus is wobbling," Feldman explains, "so we put the IUE slit at one end of the torus and followed the wobble up and down. This is the kind of observation that pushes IUE to the limit."

Observations of Comet Halley also called for creativity on the part of Feldman and his collaborators. After tracking the comet from 6 astronomical units (AU) inward to 1 AU, they picked it up again in March when Halley was just 0.8 AU from the Sun. That sounds straightforward enough, until you realize IUE was not designed to point closer than 45° to the Sun.

George Sonneborn of Computer Sciences Corporation, who is a resident astronomer at IUE, explains, "If we pointed the telescope toward the Sun, we wouldn't get any power from the solar panels; we'd have to use batteries. And we'd likely have severe damage to the telescope's optics due to heating. Also, it would completely saturate the detectors. The detectors were designed to observe the brightest stars in the ultraviolet, but the Sun is so close that it's at least twenty-five magnitudes brighter."

How did Feldman pull off his observation? He reports that, indeed, "there wasn't enough power to use all the instruments" with Halley at 0.8 AU from the Sun. So the observers "turned off the high-powered transmitter and used the low-powered one. We made two exposures of the comet and then turned the telescope 20° away, switched on the high-powered transmitter, and communicated the data. Then we went back and took two more exposures, and so on."

IUE's instruments have met another challenge: the problem of dynamic range. This problem crops up when observing objects where the amount of light at one wavelength differs significantly from that at another wavelength. Observing a particular wavelength may necessitate a very long exposure, which may leave another part of the spectrum severely overexposed. Linsky gives the example of carbon lines in the spectra of F dwarfs: "To bring up the Carbon II line at 1335 Angstroms, we have to overexpose the other end of the spectrum." After such an exposure the surface of the detector has to be thoroughly cleaned with tungsten floodlamps aboard the spacecraft. Otherwise, the excitation of the phosphorescent surface of the detector caused by the overexposure could linger, resulting in a residual image of the overexposure that remains for several days and shows up in another observation. As Sonneborn explains, such

About two hundred astronomers participated in the international conference "New Insights in Astrophysics: Eight Years of UV Astronomy with IUE," held at University College, London, in July 1986. Photo by D. Rooks.

overexposure "doesn't damage the cameras, but it could wipe out someone's observing program."

Of course, there are limits to even IUE's sensitivity and wavelength range. According to Sonneborn, most unsuccessful observations with IUE are a result of exceeding the limits of camera sensitivity. "There are many, many objects in the Galaxy that are just too faint to see with IUE," he says.

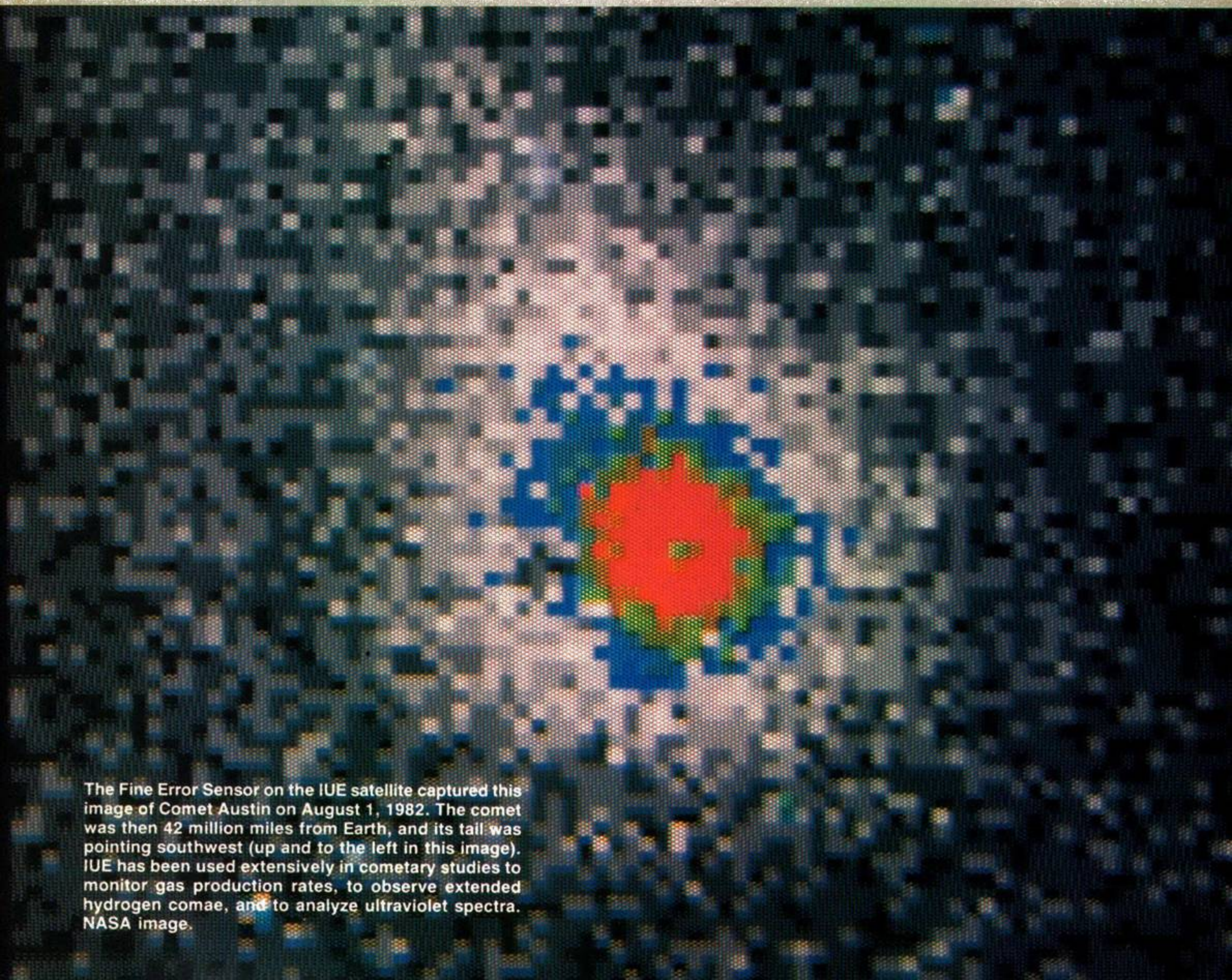
Stars of near-solar temperature can be observed down to a visual magnitude of 11 or 12 with IUE, and quasars can be seen down to about 15th magnitude. IUE can even observe hot nebulae in the Magellanic clouds that are fainter than 20th magnitude visually.

Another example of IUE's sensitivity limitations is its inability to detect systems of absorption lines in high-redshift quasars. These quasars are extremely distant objects that appear to have gaseous regions in their outer fringes that "strongly resemble our galactic halo region," says Savage. If these regions are truly analogous to the Milky Way halo, then the study of their spectra would provide a way of determining the abundances of elements in galactic haloes as they were in the distant past. Savage, who plans to eventually conduct this research using the Hubble Space Telescope, points out that "the quasar absorption systems lie right at the edge of IUE's capabilities."

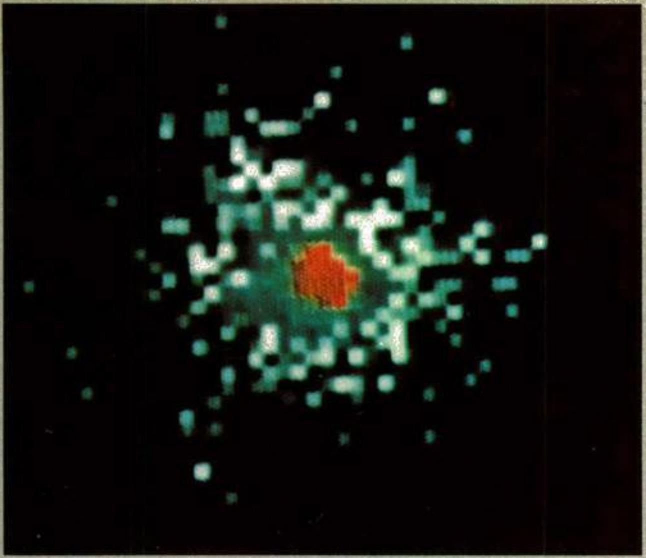
In his work Savage also feels the effect of IUE's limited wavelength range, which has a lower limit of 1150 Angstroms. "The most important spectral lines for studying the hot phase of the interstellar medium are Oxygen VI and the series of lines produced by molecular hydrogen," he says. "All these are inaccessible to IUE. I'd call the region from 950 to 1150 Angstroms the richest for interstellar observations and many other kinds of observations as well." (A follow-up mission to IUE, named Lyman after the American spectroscopist Theodore Lyman, is in the planning stage and will permit observations down to 900 Angstroms in the ultraviolet.)

Surprises from IUE

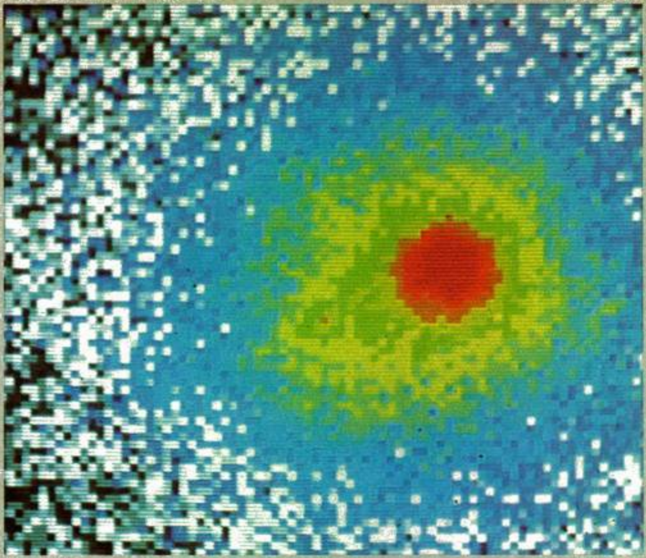
Serendipity has been responsible for some of the most important and dramatic scientific discoveries made with IUE. Feldman, for example, recalls his "most memorable moment" with IUE, which came during observations of Comet IRAS-Araki-Alcock in 1983. "As soon as we'd gotten the spectrum," he says, "we knew we had something new." The something new was sulfur — the S II line — which had never been seen in comets. "To see something new in real time holds special excitement,"



The Fine Error Sensor on the IUE satellite captured this image of Comet Austin on August 1, 1982. The comet was then 42 million miles from Earth, and its tail was pointing southwest (up and to the left in this image). IUE has been used extensively in cometary studies to monitor gas production rates, to observe extended hydrogen comae, and to analyze ultraviolet spectra. NASA image.



Observations of hot stars have allowed astronomers to study the dynamics of stellar winds and to analyze stellar abundances. Shown here is an image of the B-type star Eta Ursa Majoris taken by IUE's Fine Error Sensor. The red portion represents Eta while the surrounding white areas are fainter stars in Eta's immediate vicinity. The blue areas come from background radiation near the satellite itself. NASA image.



Cool-star research has been revolutionized by the observations of IUE. Astronomers have discovered that all cool stars have chromospheres, and they have even mapped their structure. This is a Fine-Error-Sensor image of the M supergiant Betelgeuse taken off the IUE Science Operations Center real-time display. The brightest intensity level is shown in red and the dimmest in white. Courtesy K. G. Carpenter and R. F. Wing.

Feldman says.

Other astronomers who have observed with IUE also comment on the thrill of "real-time" observing with an orbiting observatory. Guest observers have immediate access to their raw data, which is displayed on a television screen in the telescope operations center at Goddard. This allows them to modify the sequence of observations to best take advantage of target objects and observing conditions.

Observing novae, for example, involves making a test exposure to determine the required length of the final exposure, because predicting the exact brightness of the object is virtually impossible. Even with IUE's Fine Error Sensor the test exposure is still necessary, says Starrfield. "I find it pretty exciting waiting to get that first data." (This type of interactive observing, although prized highly by astronomers, won't be possible with the Hubble Space Telescope. The Space Telescope staff is developing sophisticated software to automate the schedule of observations.)

One area of astronomy revolutionized by IUE is cool-star research. Before IUE was launched, says Linsky, "all we had on cool stars was the photospheric spectrum in the optical and the Calcium II H and K lines. Aside from that glimpse we had zero information." With IUE, however, it became possible to study and map out the structure of stellar chromospheres and transition regions (the region between the chromosphere and the corona), from the base of the chromosphere all the way up to the level where the temperature reaches 200,000 Kelvins. "What we've found," Linsky says, "is that all stars cooler than the Sun have chromospheres. We suspected they did, but now we know."

One of the early results obtained using IUE was the discovery of what Linsky calls the transition region dividing line — "a relatively sharp division in the Hertzsprung-Russell diagram between solar-type stars and something very different from the Sun."

These "different" objects are stars that have strong chromospheres but weak coronae as a result of mass loss through a cool stellar wind. They form a new class of stars, called hybrid stars, which literally could not have been identified without IUE since the distinguishing characteristics of these stars are only visible in the ultraviolet.

With hot stars IUE has helped astronomers study mass loss due to stellar winds and analyze stellar abundances. Lines arising in widely different parts of the wind — from those formed in the photosphere to those formed in the farthest periphery — are visible on a single spectrum taken with IUE, which permits the study of the dynamics of the wind and the correlations of variations in the wind.

The study of the abundance of the various elements in stars benefits from resonance lines (spectral lines involving transitions from or to the ground state of an atom) that show up on IUE spectra and that can't be observed at optical wavelengths. IUE has been particularly valuable in the study of peculiar A stars and mercury-manganese stars. For example, David Leckrone of Goddard Space Flight Center has used IUE data to measure the abundance of boron in several mercury-manganese stars. Boron is one of the least abundant elements that can be synthesized in stars: it's about a billion times less abundant than hydrogen. Leckrone has found that the measured amount of boron in mercury-manganese stars is much higher than that found in the Sun, a difference nuclear synthesis can't account for.

IUE is particularly well-suited to observing hot stars because they radiate more of their energy in the ultraviolet than in the optical spectrum. Unfortunately, interstellar dust absorbs and scatters ultraviolet light, so not all hot-star observations are easy to make.

The study of cataclysmic variables, or novae, has also been advanced by IUE. Wilson puts it succinctly: "Before IUE we barely knew what novae were, and now the basic understanding is there." As in cool-star research, IUE's observations of novae uncovered an entirely new class of object. Starrfield and his collaborators weren't expecting to uncover the new class of novae when they undertook an IUE observing program in 1981 and 1982.

"This is a good example of serendipity," says Starrfield, "since we were just trying to find out as much as we could about the dynamics of novae." Instead they found a class of novae that has strong emission lines of neon, magnesium, and aluminum instead of the strong lines of carbon, oxygen, and nitrogen normally present. Starrfield feels that "the only way we can explain these objects is to say they're an entirely new class of novae. They must be stars with more processed cores."

Starrfield's group has observed nearly a dozen novae with IUE over the last eight years, thanks to what's called a target-of-opportunity observing program. Proposals for this program are submitted and peer-reviewed like other observing proposals, but no specific dates and shifts are assigned for the observations. Instead, observers are granted time when the appropriate event occurs, such as the appearance of a comet or nova. In the case of a really significant event, a supernova for instance, scheduled observers might be bumped to allow observations of the unexpected event. The observers who get bumped are then rescheduled for a later date.

Research with the IUE Archive

All the observations ever made with IUE — more than 50,000 so far — are collected in the IUE Archive at Goddard Space Flight Center. Observers have exclusive rights to the data they obtain for six months after the observation; after that time the data pass into the public domain. Far from being a musty stack of useless records, the IUE Archive is widely regarded as an extremely important scientific resource. Savage calls it "a precious resource for future discoveries. Astronomers can request data and learn new things about whatever they're studying. If one researcher is accumulating stellar data, for example, an interstellar-medium person can come along and use the same data."

Frequently spectra contain information that went unused — perhaps even unnoticed — by the original observer. In the case of novae some spectral lines remain unidentified. Says Starrfield, "There's certainly more information that can be gotten out of the data. The archive is a library of ultraviolet data on novae, and people will have it to analyze for future projects."

The IUE Archive is already heavily used by the astronomical community. Project scientist Kondo notes that about one-sixth of the ninth-year project proposals was "purely archival." At the IUE conference last July it wasn't surprising to spot a paper subtitled "Another Insight in Astrophysics from the IUE Archive."

The archive will be funded even after the death of the satellite, Kondo reports. Partly in an effort to bolster its scientific output, NASA is placing greater emphasis on archival research these days. It has recently created the Public Domain Data Analysis Program, which covers past projects such as the Infrared Astronomical Satellite (IRAS) and the Einstein X-Ray Observatory, as well as IUE.

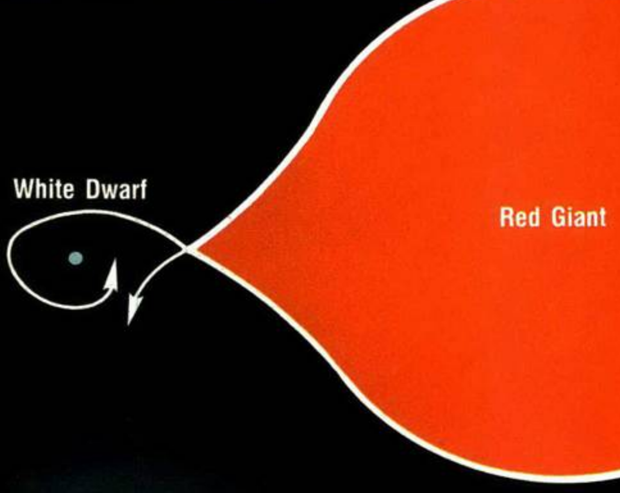
Of all these projects IUE is the only one still functioning. Gone, at least for now, are the days when simultaneous observations of a single object could be scheduled at several different wavelengths. In her talk at the conference last July Ulrich spoke of the planned simultaneous observations of active galaxies using IUE and the European x-ray satellite EXOSAT. The program was terminated because "the EXOSAT mission ended before the observations could be made."

A few years ago a successful attack at all wavelengths was made on the recurrent nova RS Ophiuchi. Satellites, including EXOSAT and IUE, were used in conjunction with ground-based optical and radio telescopes. This achievement was particularly notable because, as Starrfield remarks, "on target-of-opportunity objects like novae it's very difficult to obtain simultaneous observations. It's desirable, but it's not easy."

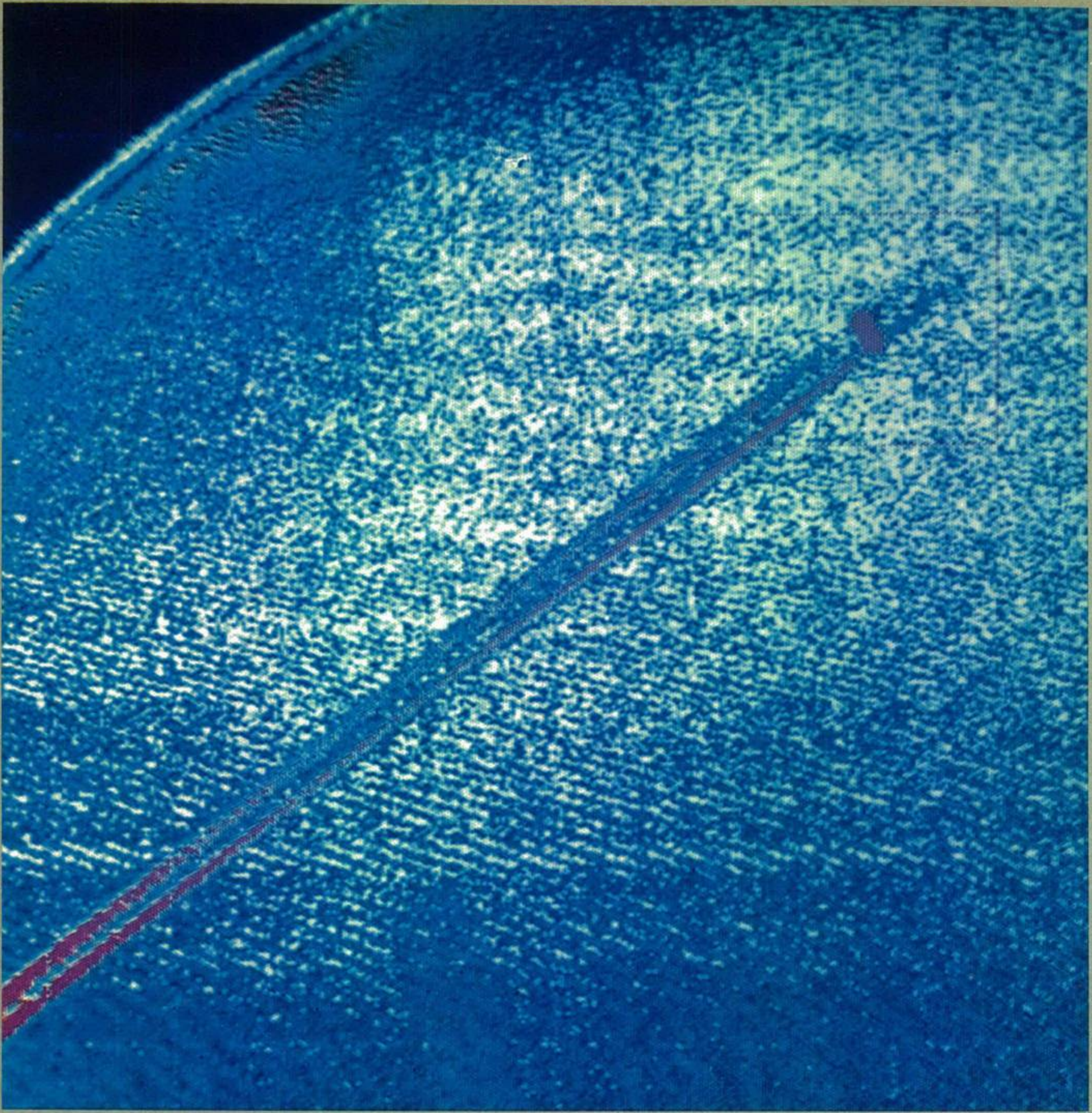
In cool-star research, observations in the ultraviolet and x-ray parts of the spectrum have complemented each other nicely. Linsky explains that the x-ray telescopes aboard the first two High Energy Astrophysical Observatories, HEAO I and Einstein, "couldn't see chromospheres, and IUE couldn't see coronae. We knew almost nothing in the x-ray until HEAO and almost nothing in the ultraviolet until IUE, so both opened up new observational windows." In general, as Savage says, "the best way to make progress in any astronomical study is to use every kind of observation you can, rather than limit yourself to one kind of observation."

The Einstein Observatory lasted only three years, and

How Novae Form



IUE has improved our knowledge of novae to the point that astronomers now feel they have a basic understanding of the phenomenon. All novae seem to occur in binary systems containing one white dwarf and one star on its way to becoming a red giant. As the latter star grows larger, its atmosphere becomes distended to such an extent that mass flows over to the white dwarf. This material slowly piles up on the surface of the white dwarf until the temperature reaches a critical value. At this point the entire built-up layer suddenly undergoes nuclear burning, which causes a dramatic brightening. The process repeats on a time scale that can last from years to centuries.



These two IUE spectra of the central region of globular cluster NGC-6752 show evidence of something very hot and bright. Conventional theory predicts, however, that no hot, bright objects should be located in globular clusters. One possible interpretation is that these spectra reflect the influence of a massive black hole at the center of the cluster. NASA image.

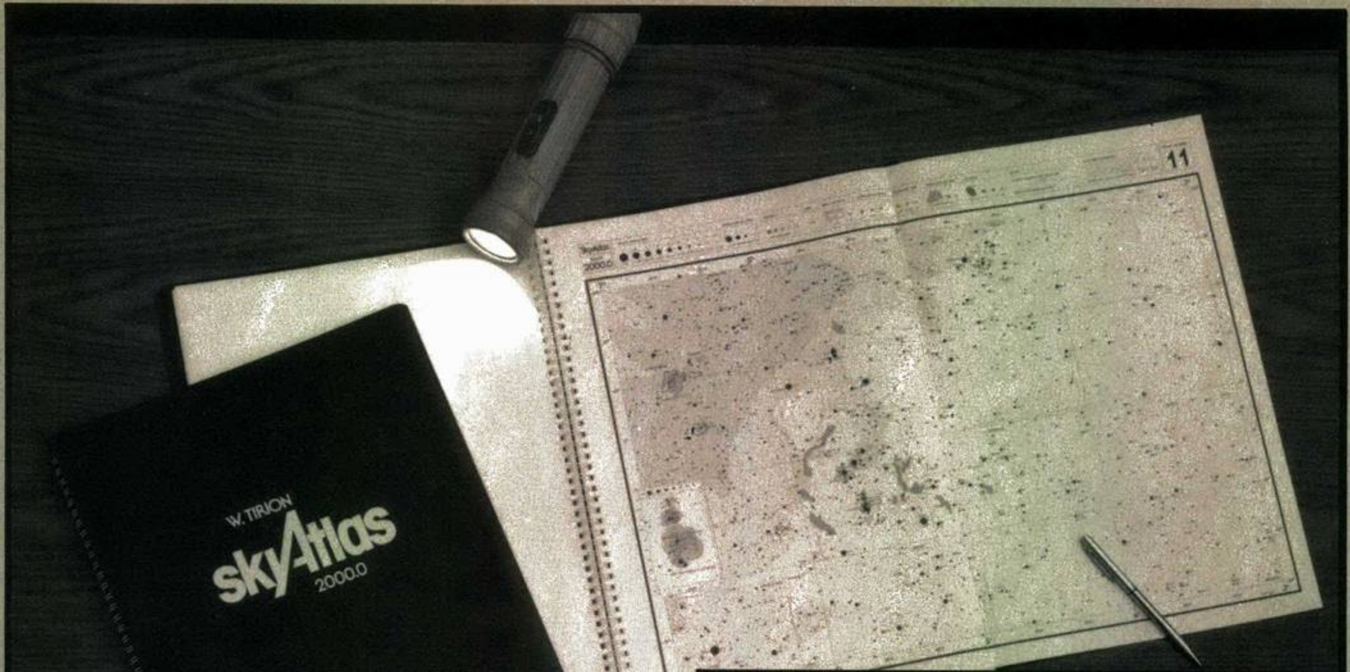
IRAS just under one year. IUE is still flying. Thanks to its long life, IUE has made a deeper imprint on the astronomical community than any previous orbiting observatory. In IUE's first nine years, 755 U.S. astronomers, out of a total membership of nearly four thousand in the American Astronomical Society, conducted research programs with the satellite.

Kondo points out that "IUE has no vested interests. It was designed from the first as a guest-observer facility." Although one might think the same people would use IUE year after year, Kondo says there has been an annual turnover of between 30 and 50 percent in IUE observers.

That's not to say the entire astronomical community immediately recognized IUE's potential. Among solar system astronomers, for example, those who were already doing ultraviolet research from rockets first used IUE. Feldman recalls, "It wasn't as though the whole solar system community jumped on the bandwagon." Gradually, however, IUE has earned a permanent place in the affections as well as the research and publication lists of many astronomers.

Starrfield sums up the impact of IUE: "I don't think of IUE as a small telescope out there; I think of it as an unmatchable instrument."

Lys Ann Shore is a writer and editor living in Socorro, New Mexico. She holds a Ph.D. in the history of science from the University of Toronto and last contributed "Site Wanted: Three Domes, Stellar View" to the August 1986 issue.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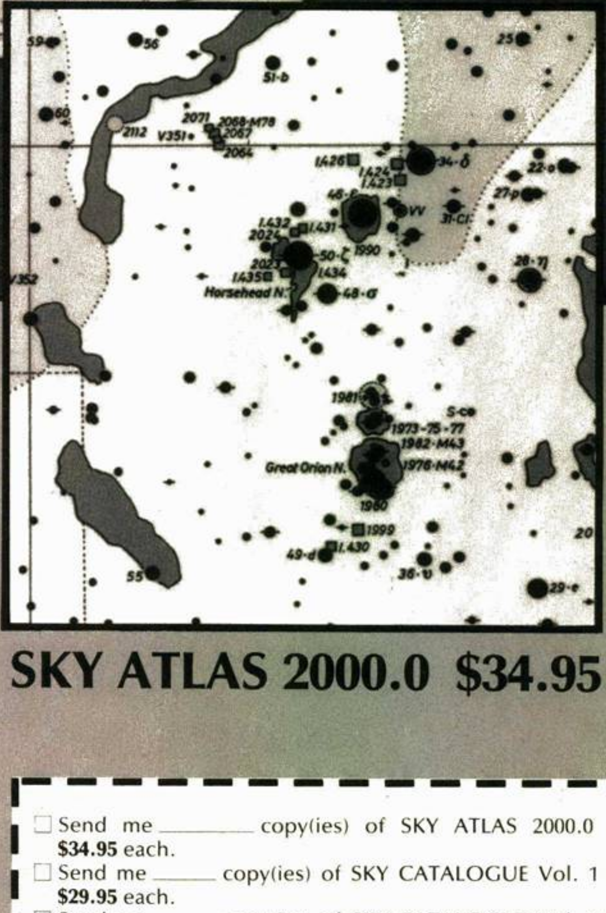
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ASTRONOMY
Forum

The Last Days of Richard Carrington

One of Dr. Watson's still unpublished tales about his friend Sherlock Holmes is the mystery of the gentleman who stepped back into his house to get his umbrella and was never seen again.

That fictional event has a true counterpart in the case of the nineteenth-century astronomer Richard Carrington, who disappeared immediately after an inquest into his wife's death. A week later he was observed entering his house at the Devil's Jumps — and was never seen alive again.

Carrington, the son of a prosperous brewery owner, was born near London in 1826. He entered Trinity College, Cambridge, in 1844 to study for a career in the church, as his father wished. He also attended lectures on celestial mechanics by James Challis, that unfortunate astronomer who in 1845 achieved a sort of immortality for muffing the chance to discover the planet Neptune just when it was within his grasp.

"The tenor of my mathematical studies," Carrington later wrote, "acting on mechanical propensities to which I had always been addicted made it clear to me that I was more naturally adapted to the pursuit of some physical science involving observation and mechanical ingenuity." He decided to become a professional astronomer and, after taking his degree in 1848, induced his wealthy father to stake him in his chosen career.

In 1849 Carrington was appointed observer at the University of Durham in northeastern England. During the next three years he gained practical experience with the university's 6.5-inch equatorial refractor, observing star positions, minor planets, and comets, and reducing his observations. He quickly established a reputation as an up-and-coming astronomer by publishing reports of his work in the *Monthly Notices of the Royal Astronomical Society* and the European journal *Astronomische Nachrichten*.

Carrington saw little opportunity to advance or to pursue his own astronomical research at a provincial university. He resigned his position in 1852 and, subsidized by the considerable income of the brewery, erected a home and observatory at Redhill, a village twenty miles south of London in the county of Surrey. By 1853 the observatory was equipped with a transit and a 4.5-inch equatorial refractor, and he began a survey of all the stars to 11th magnitude within 9° of the north celestial pole.

The result of Carrington's work from 1853 to 1855 was published in his *Catalog of 3,735 Circumpolar Stars Observed at Redhill*, together with nine associated maps. The catalog's high standards of excellence earned him the Royal Astronomical Society's gold medal in 1859.

Carrington is chiefly remembered, however, for his solar work. In 1853 he decided to observe and record sunspots and sunspot groups over an entire 11-year solar cycle in order to determine the Sun's true period of rotation and the orientation of its axis. In 1861, when he became heavily involved in the operation of the brewery, he stopped his observations, but during a period of seven-and-a-half years he made 5,300 observations of the Sun, an average of almost two per day. He published his results in 1863

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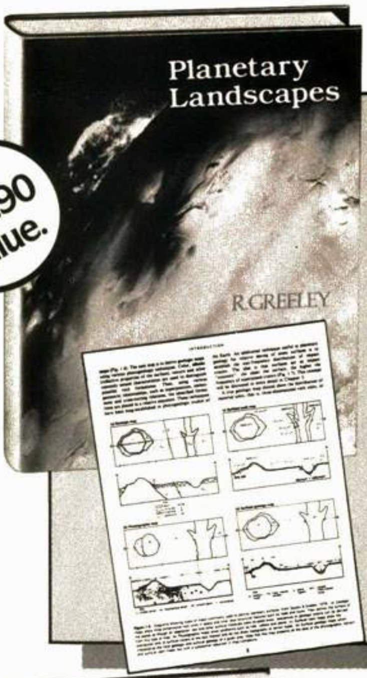

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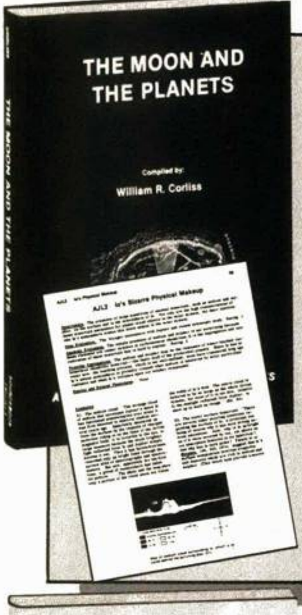

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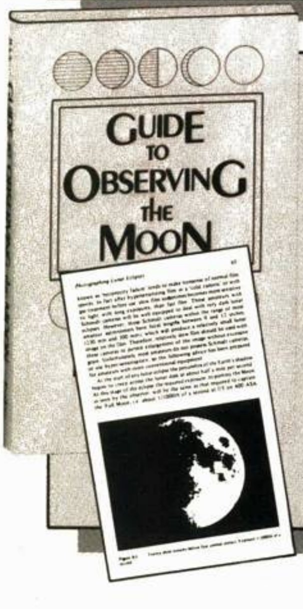

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in a monograph bearing the elegant title, *Observations of the Spots on the Sun from November 9, 1853 to March 24, 1861, Made at Redhill.*

He found that the farther sunspots are from the solar equator, the longer their periods of rotation. A spot on the equator makes the circuit in just about 25 days, while one at a solar latitude of 45° takes 27.5 days to complete a rotation. The Sun, he concluded, could not be a solid body because it didn't rotate at a constant rate.

Carrington was the first astronomer ever to witness a solar flare. On September 1, 1859, he was startled to see a brilliant flash of light suddenly appear over a large group of spots. More intense than the surrounding photosphere and appearing to be in motion, the flash lasted only five minutes before disappearing. The sudden solar outburst was followed by an intense magnetic disturbance on Earth and accompanied by a magnificent auroral display visible down to the low latitudes. That remarkable occurrence was the first observed example of the direct influence of solar events upon the Earth.

When his father died in 1858 Carrington took over the management of the brewery, an enterprise of considerable magnitude. He became so involved with its operations that by 1861 his observing career had effectively ended. A serious illness in 1865, from which he never fully recovered, forced him to sell his prosperous business.

Carrington and his wife retired to Churt, a Surrey village in a wild and picturesque heathland thirty miles southwest of London. He purchased nineteen acres of land, which included three squat, conical hills known locally as Devil's Jumps. Atop the sixty-foot-high Middle Devil Jump, and overlooking a depression in the heath called the Devil's Punchbowl, he built a new observatory. In this setting ten years later a tragic scenario was played out.

On November 17, 1875, Carrington's wife, Rosa, was found dead in her bed — an apparent suicide. An inquest was held four days later before the West Surrey county coroner. Witnesses testified that Mrs. Carrington had been in ill health and was in the habit of taking chloral hydrate before retiring.

Chloral hydrate had been introduced into medicine only six years earlier. It induces a natural-like sleep when taken in therapeutic doses but causes addiction when taken habitually. Among the symptoms of an overdose are breathing difficulties and a slow or irregular heartbeat.

The coroner's jury found that Mrs. Carrington had died from suffocation, but there was no evidence to show how she suffocated. The jury harshly censured Carrington for inadequate supervision of his wife during her illness, but took no further action.

Carrington returned home immediately after the inquest, dismissed his servants, and was not seen for a week. On November 27 his neighbors saw him enter his house. He never reappeared.

After some time the neighbors sounded the alarm and police inspector Joseph Hibbard was sent to investigate. He forced his way into the house but found no sign of Carrington, though one of the servants' rooms was locked from the inside. Hibbard forced the door open and found Carrington lying dead on a mattress between the bed and the fireplace. A handkerchief was tied around his head. Hibbard locked up the house and arranged for a guard.

He returned the following day with Robert Oke Clark, a surgeon from the neighboring town of Farnham. In the dining room they found Carrington's carrying bag and in it was an empty chloral hydrate bottle. Four more chloral hydrate bottles were scattered around the room. They entered the servant's room and Clark examined Carrington's body.

Another coroner's jury was empaneled on December 4. Clark testified that his post-mortem showed the deceased's body to be free of chloral hydrate. He concluded that Carrington had died from "sanguineous apoplexy" — a stroke — and had fallen down in a fit. Carrington had apparently applied a poultice of tea leaves in a desperate effort to relieve the pain. The jury returned a verdict of "sudden death by natural causes."

Thus were the questions about Richard Carrington's death laid to rest. Of Rosa Carrington's death, however, three questions remained. Did her husband become so overwhelmed by the condition of his invalid wife that he gave her an overdose of chloral hydrate? Did a compassionate coroner's jury, in a gesture of British fair play, choose to ignore evidence? And finally, what really did happen that November 17 at the Devil's Jump?

Kenneth Weitzenhoffer
Brooklyn, NY

Hot Tub Astronomy: A Fire on the Moon

The cold breeze was refreshing as it blew across my face and shoulders. The heat from the water steamed up and around us as my husband and I sat in the hot tub, prepared to watch the Perseid meteor shower. How wonderful — the universe was about to provide us with a show. No Moon tonight. All the better.

Without the Moon shining on the whitecaps and making them sparkle, the windswept Pacific appeared calmer than it really was.

"You forgot the binoculars," said my husband.

"We won't need them to watch meteors," I replied, grasping for a reason to avoid getting out of the warmth. I was sorry I didn't have the binoculars later.

I sipped my cold drink and looked at the northeast area of the sky. This wasn't the easiest area to see because a building stood in the way.

"That's funny, I didn't think there would be a Moon tonight," said Bob, sounding puzzled. "But there it is."

I looked toward Catalina Island. A crescent Moon hung over the island, where the Moon always sets at this time of year.

"We must have mixed up the time," I said. You can't argue with a Moon you can see. And it certainly was there. "It's not very bright though. It won't hurt the meteor viewing." I looked back toward the east to watch for meteors.

"Look at the Moon now!" said Bob. "It almost looks as if there is a fire on it." I looked back quickly. At first I didn't see it. Bob's eyes must be better than mine. I continued to stare. Then I saw it! Sure enough, a tiny flame had appeared and flickered faintly on the top point of the crescent.

"There it is again! See it?"

"Yes! What could it be?" My mind searched for and dismissed an assortment of causes for the phenomenon. A spark of Sun on an abandoned vehicle from a Moon landing? A meteor crashing into the Moon? An airplane fire? No! None of the above. A fire on the Moon. Impossible, but that's exactly what it appeared to be. And, as we continued to stare silently, the flame grew larger. There was no missing it now.

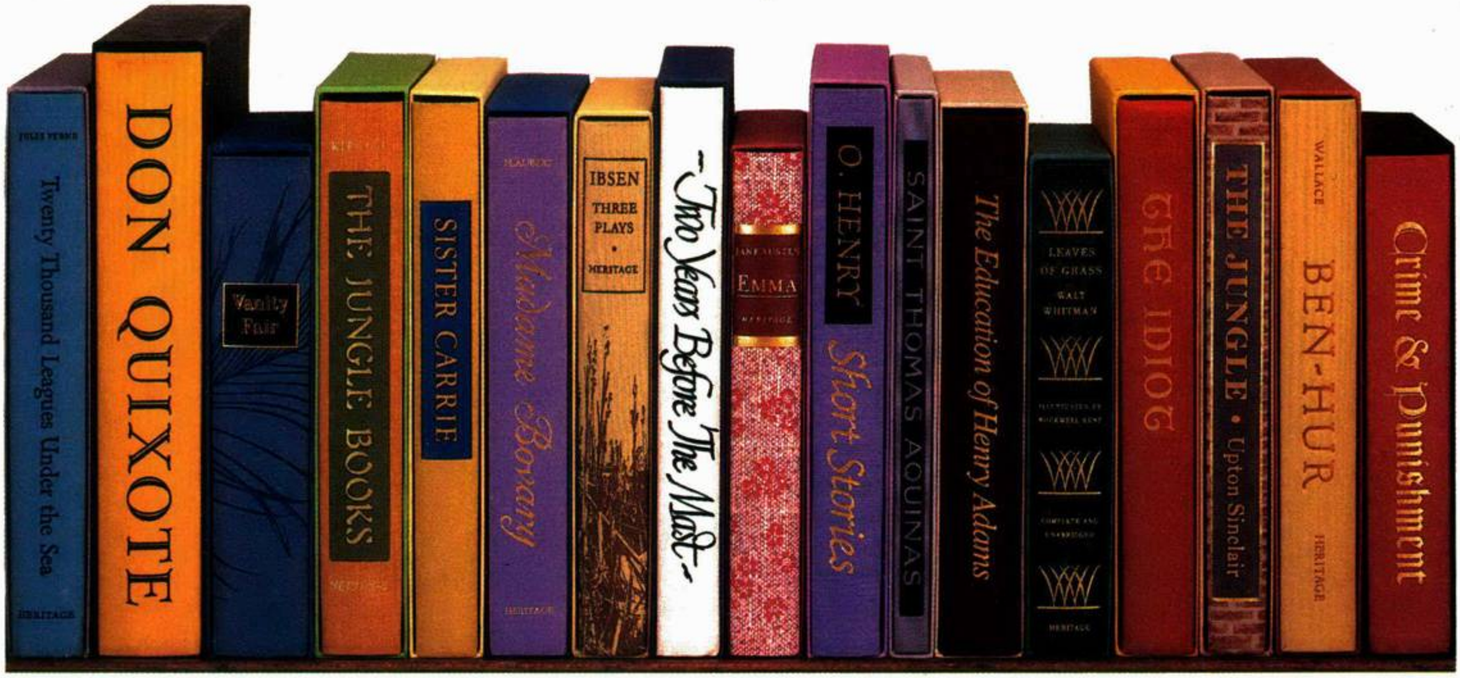
Then the flame broke off of the Moon and floated slightly below it. At this point the flame looked like Venus. A very bright Venus right under the Moon. Then the Moon did a strange thing: it slowly faded from sight.

Only the very bright light was left. It grew brighter, outshining the background stars. Although it didn't go up or down, the light seemed to grow a little larger.

"Do you suppose it's getting closer?" I asked.

"That could be why it seems to be getting brighter. It's either getting bigger or closer."

"Should we be doing something?



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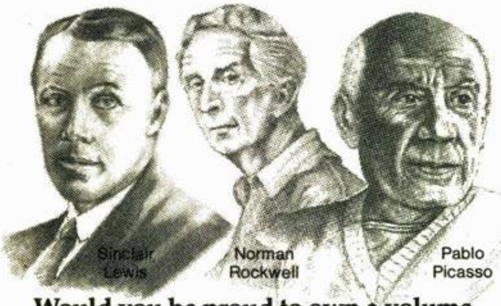

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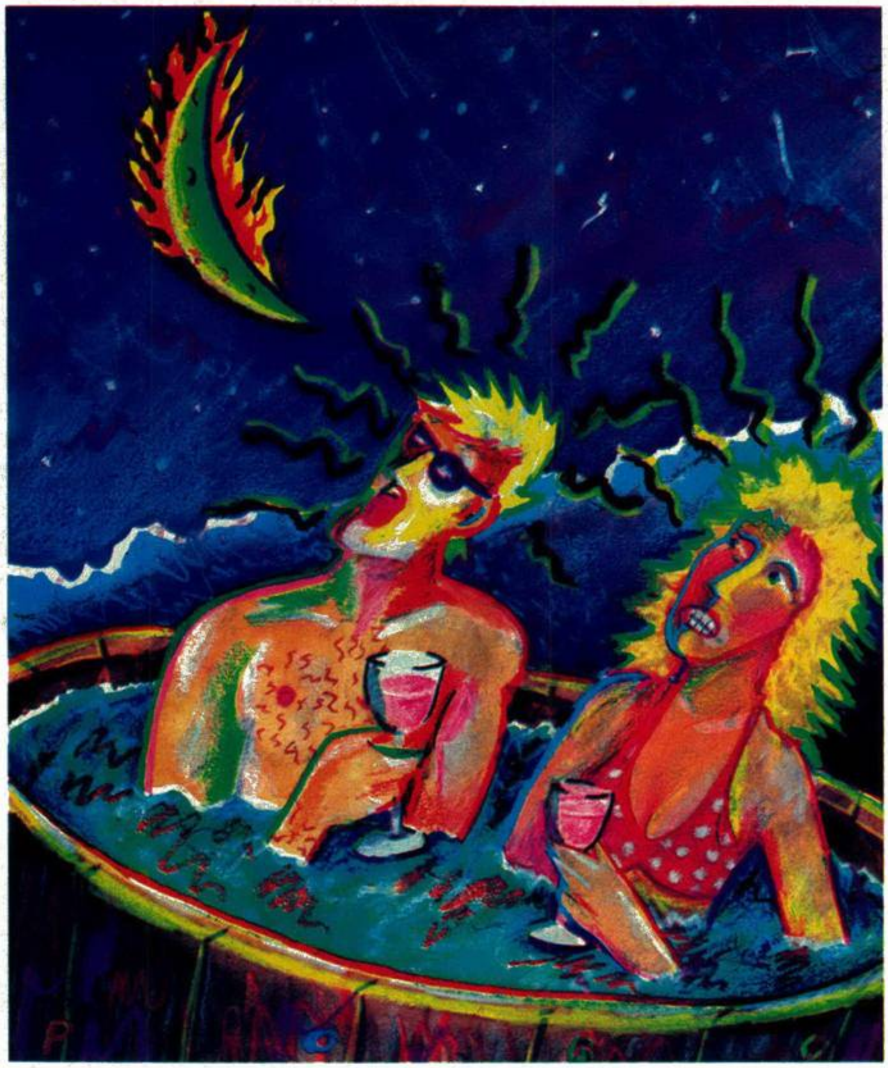


Jim Pogorzelski

Like getting out of the way?"

"Probably."

We sat transfixed. Hypnotized.

"Look, it's changed to orange!" I said. There was a bright streak like moonlight across the black water. Still it was silent.

Bob was about to get out of the tub to get the binoculars when abruptly the light went out! Completely and silently out. All was dark again.

For the next five or six seconds we sat and stared at the void. Before we could speak the light went on again! It was still orange and only slightly lower than we remembered.

It lit up the water for a few more seconds and then disappeared. We watched a while longer just in case it reappeared.

The next day, thanks to the local newspaper, we learned what the light was. In a very small box on an inside page, we found this report.

Vandenberg, Calif.: The Air Force admitted today that a missile misfired at 11:15 last night and had to be destroyed two hundred miles off the coast. Many people reported the bright light in the sky.

Beverly Mosier
Laguna Beach, CA

The Scientific and Cultural Heritage of Allegheny Observatory

At Allegheny Observatory in Pittsburgh, Pennsylvania, the cutting edge of astrometric research is artfully blended with instruments created by John Brashear and Henry Fitz. Working on the restoration of the Fitz/Clark 13-inch refractor located there, I had the opportunity to explore Allegheny's unique heritage.

Many firsts have been attributed to this refractor. It was used by Samuel Pierpont Langley and James E. Keeler to determine the temperatures of the Sun and Moon and to discover the consistency of Saturn's rings. In addition, the lens of this telescope was probably the only one in history to be stolen and held for ransom!

I found the 13-inch refractor housed in its "new" home. (In this case "new" means as of 1912.) The refractor was operational at the original Allegheny Observatory when Abraham Lincoln was president; the observatory's current location is just a short drive from the original site.

Under the patient and encouraging eye of Dr. George Gatewood, director of Allegheny Observatory, I began work on the renovation. The 13-inch Fitz/Clark was not born again from its own ashes like a phoenix. Instead, this instrument has survived the past in remarkably good shape and only minor changes have been made over the years.

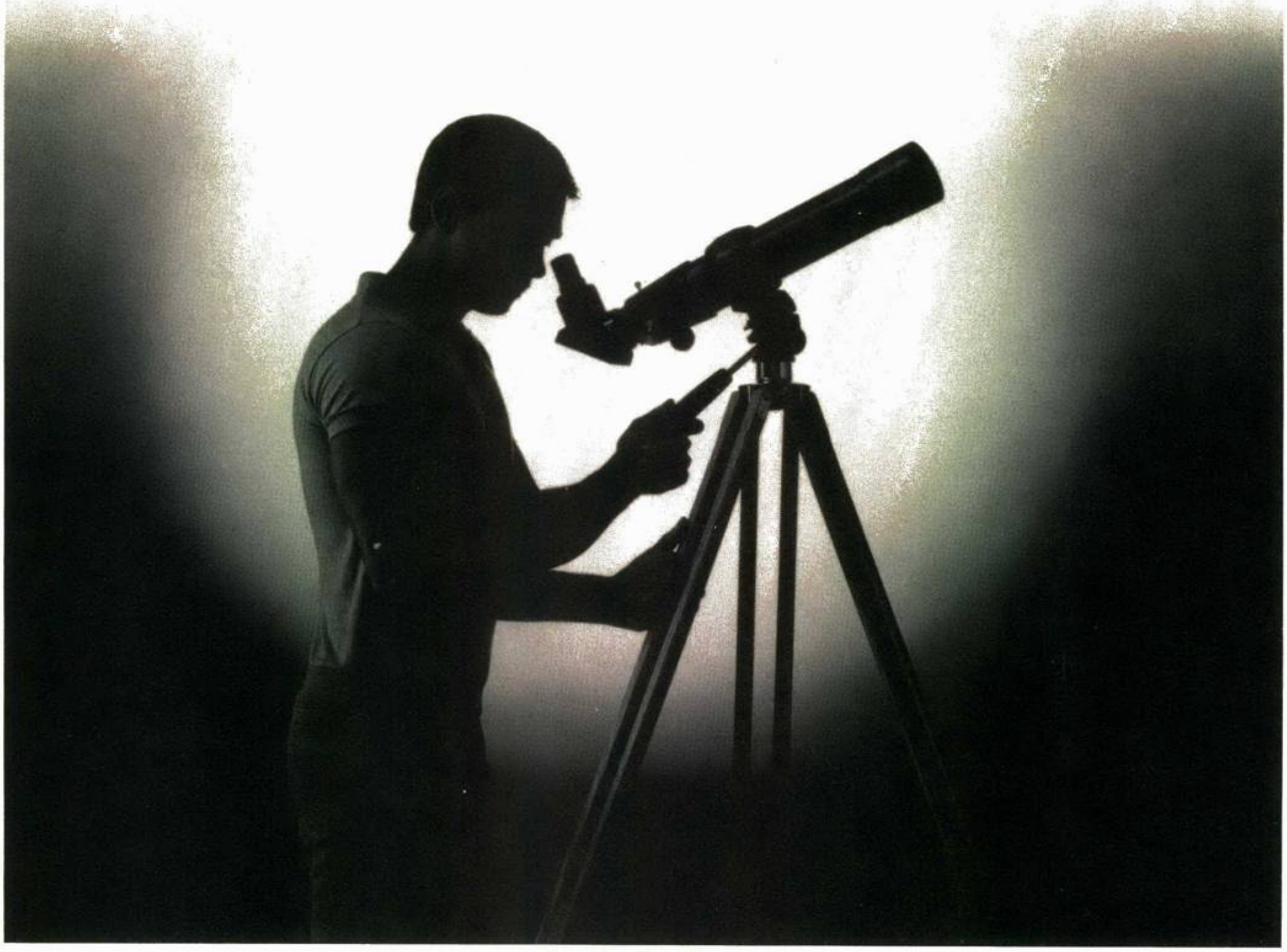
The original wooden tube was replaced long ago with a metal tube, which has been painted blue, and much of the brass adornment has been painted black. The finder, the electric clutch for the gravity drive, and the right-ascension slow-motion controls are all decidedly twentieth century.

Brass, common to both the scientific instruments and the works of art of the period, adorns Fitz's remarkable refractor. This beautiful goldlike metal — so easily shaped and machined — adds a distinctive and esthetic quality to the instrument, a quality totally unmatched by today's antiseptic stainless, aluminum, or other exotic alloys. But Fitz went a step further: blending both rose-colored and yellow-colored brass pieces side by side to create a functional work of art.

Removing tarnish from the unpainted brass surfaces was the first step in the refractor's restoration. This step allowed us to inspect the brass pieces and to determine how much more work would be required. Some of the pits and marks we found on the brass were obviously a result of the original casting, though most of them were probably a result of Pittsburgh's airborne pollutants.

We removed the tailpiece, working around the refractor's busy schedule. (The telescope is used almost nightly by the staff as well as by the public.) With the aid of assistant astronomer George Fennell I took the tailpiece to the observatory's machine shop, where after disassembly each piece was polished with red jeweler's polish and a polishing wheel. Little else could be done because of the numeric engraving around the refractor's circumference. The red rouge brought a mirrorlike shine to the tailpiece and to various knobs and wheels.

The next problem was maintaining this lustrous shine. I chose to use Tung Oil because it neither discolors with age nor dries translucent. So, following a final dry polishing to remove any residual rouge and reassembly, the exterior brass of the tailpiece was coated with Tung Oil. The streakless, coated piece was then left to dry in a



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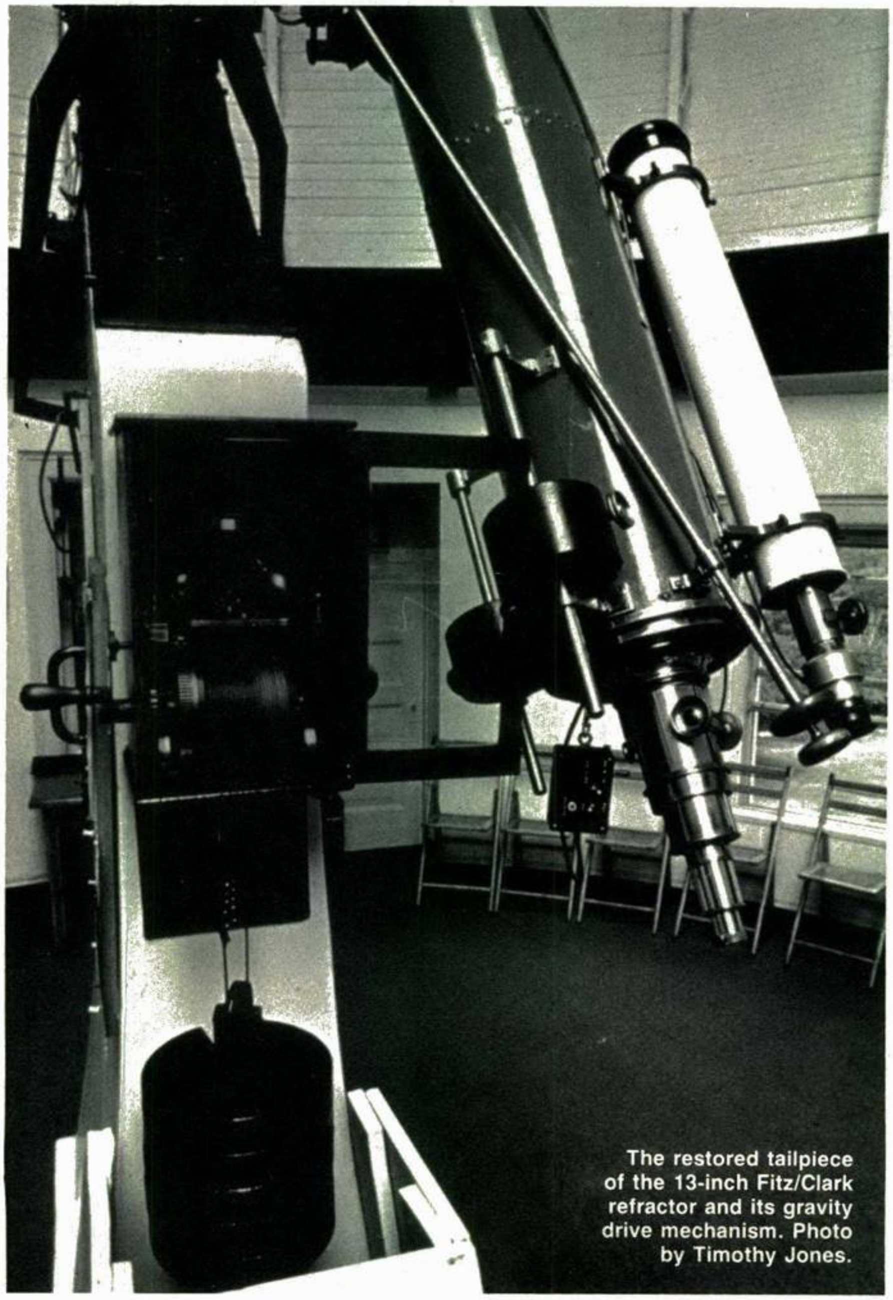
dust-free humidity-controlled room, a type of room common to observatories and research facilities. A second coat of oil was applied twenty-four hours later. After the reinstallation of the tailpiece, the next and far more challenging operation was restoring the objective cell.

We decided to leave the cell intact, because no one wanted to risk damaging the nearly priceless 120-year-old objective lens. Leaving it in place, however, presented a new set of problems that included the careful masking and sealing against the dust that I and the loose brass filings would be creating. Yes, filings. With all due apologies to antique dealers, removing deep pits and marks with a fine file proved to be the only option. After all, Allegheny Observatory is a functioning research facility, not a museum.

We carefully used fine files so we wouldn't change the exact shape of the cell. One by one all the surface pits were removed, and the curved and convoluted surfaces restored without alteration. After filing, we sanded with emery cloth of medium and fine grit a number of times.

We removed sanding marks with a fine grit polishing compound, which is used for auto body work, and a buffing wheel. As with the tailpiece, the fine polishing of the cell was done with red rouge and a buffing wheel.

Once we had perfected our restoration techniques, we filed, sanded, polished, and coated the remaining exposed brass with Tung Oil. However, the Tung Oil applied to the telescope in the uncontrolled environment of the dome fogged the surfaces because the humidity was high on the day of application. The fogged coat had to be removed and another coat of Tung Oil applied on a less humid day.



The restored tailpiece of the 13-inch Fitz/Clark refractor and its gravity drive mechanism. Photo by Timothy Jones.

The next step was gently scraping small amounts of built-up black paint from the brass pieces that we suspected might contain iron. All proved to be brass, and with commercially available paint remover we stripped off three separate coats of paint.

At this point we had another glimpse back into history. Because the original parts were handmade, some identification marks were necessary for fitting and refitting; I found these marks after the paint was removed. Apparently Fitz had stamped the numbers 1 and 2 on the uprights to distinguish them and had stamped corresponding numbers on both ends of the counterweight shafts as well. The handmade bolts were not interchangeable and had to be heated for removal. These smaller pieces also were taken to the machine shop for filing and polishing. Two coats of oil for the pieces and forty-eight hours later the telescope was back at the dome for reinstallation.

The only alterations we made during the restoration were on the front counterweight set. The original brass shaft had been removed and replaced with one of iron: the motive for the replacement is unknown. In the interests of art and continuity, a local firm was commissioned to provide a new yellow brass shaft. Following some careful drilling and tapping, new rose brass bolts were installed and the Fitz/Clark was near completion.

After spending hours in close association with a great work from the past, I developed a respect and even love for artisans of Fitz's class — not only from a technical and mechanical standpoint, but from a scientific standpoint as well. I have used this telescope on many occasions and was overwhelmed by images of great contrast and definition that justified the skills of men like Brashear, Fitz, and Alvan Graham Clark.

The refractor has a place in the past, but it also has a place in the future. The restoration makes it ready for the next generation of astronomers and visitors to discover and rediscover the mysteries of the night sky above Pittsburgh.

With the Fitz/Clark and its two Brashear companions — the 30-inch refractor now with Gatewood Multichannel Astrometric Photometer, and the 31-inch reflector with its Mellon spectrograph, both seventy years old — Allegheny Observatory preserves history and science as both a research institution and as an innovative museum.

Timothy R. Jones
Butler, PA

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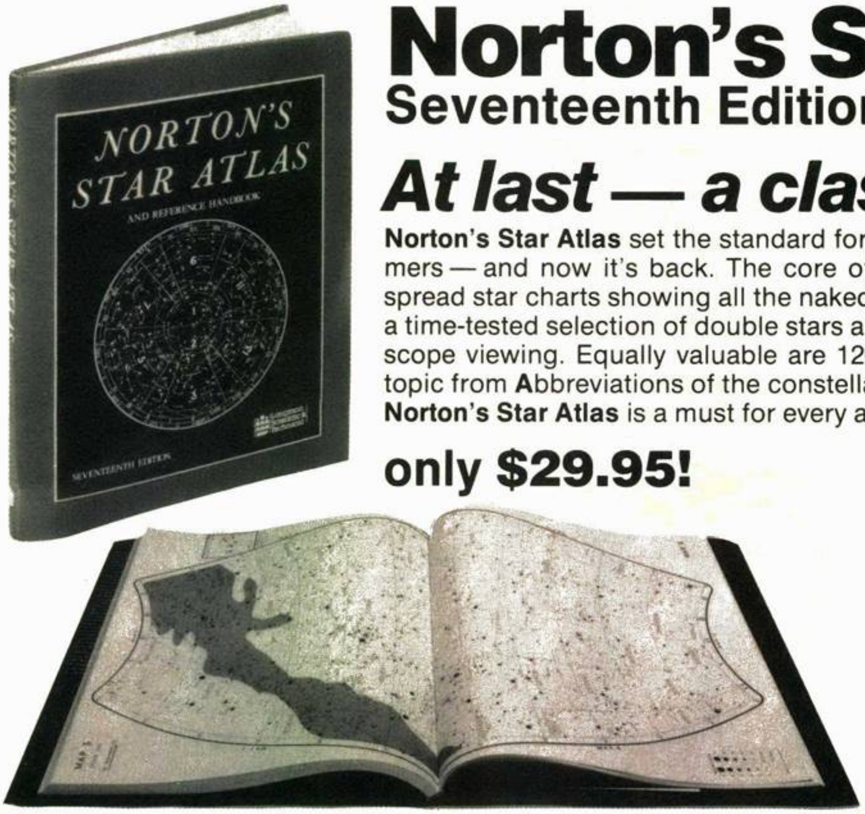

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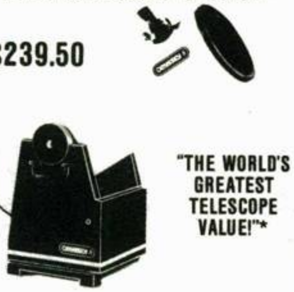

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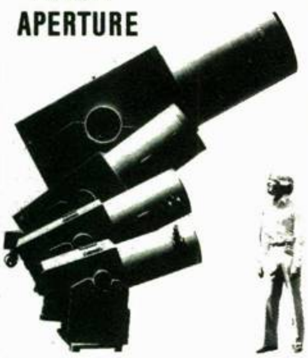

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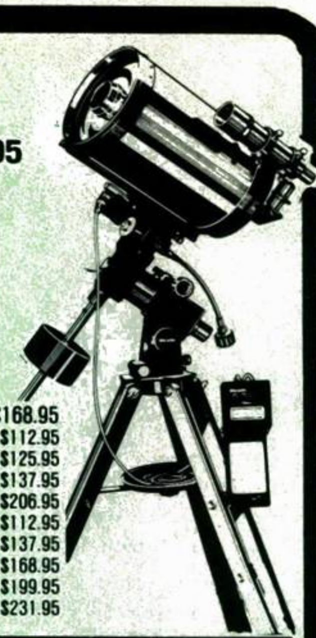

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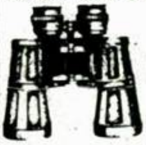

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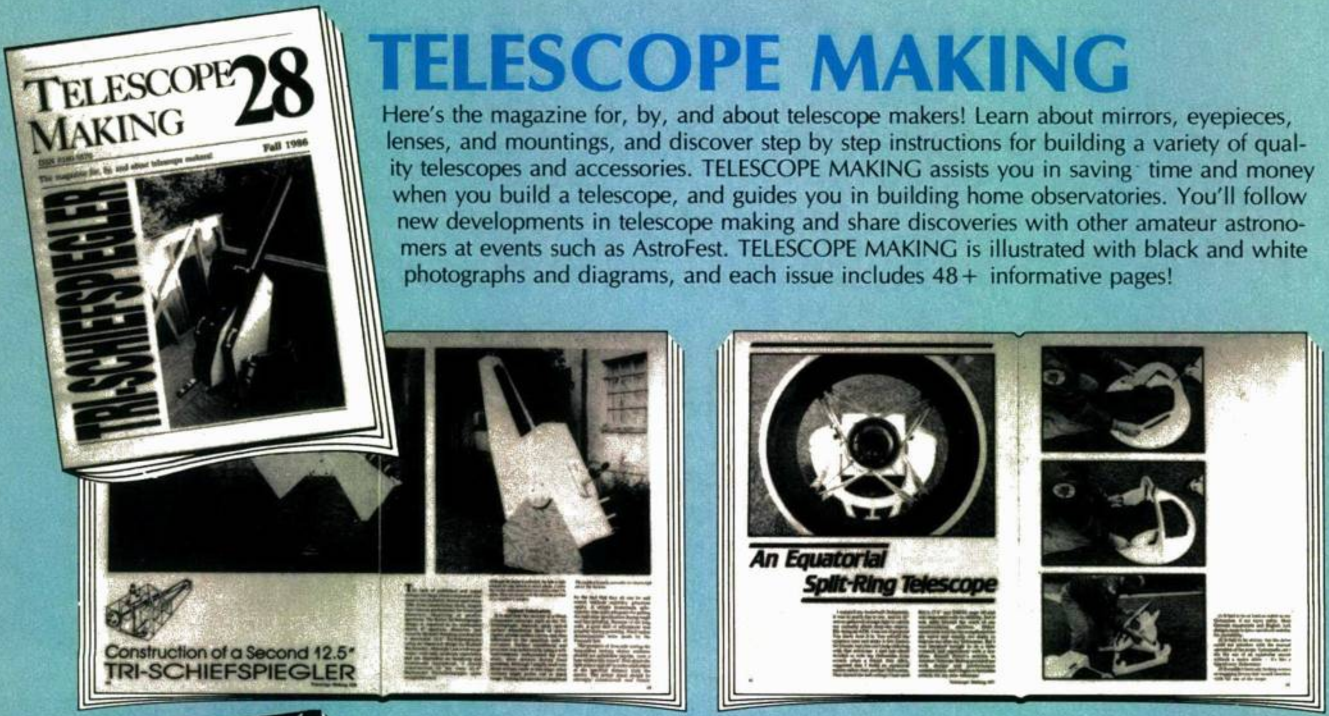
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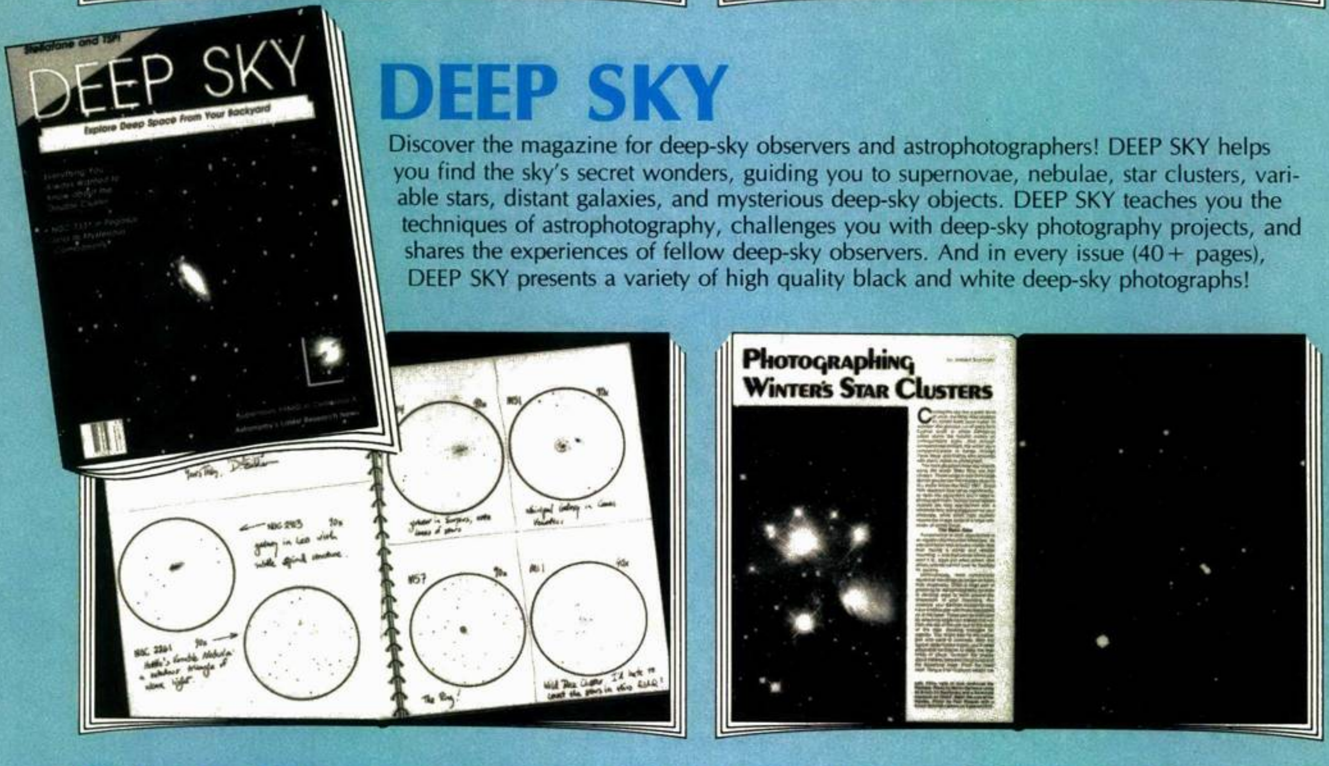
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ASTRONOMY
In Focus

Questions about ECLIPSE.BAS

Sir/ I have three questions about the eclipse program in "Eclipse Predictions on Your Computer" by Mark Whiteman (Gazer's Gazette, November 1986).

What does the E that appears in line 420 mean? Should (UM) in line 860 be (MU)? And, in line 1430, should T1% be T1$?

S. N. Turner
Locust Grove, VA

Sir / I don't think the terms DEF FN LESS(X), %, FIX, and PRINT USING in the ECLIPSE.BAS program in the November issue can be called generic BASIC terms. After searching through various books, I came up with definitions for % and FIX, but I couldn't find out what the others mean.

Josef Prall
Carollton, TX

— Two typographical errors crept into the published version of ECLIPSE.BAS. In line 1430 T1% *should be* T1$. *The transposing of characters in line 860 does not affect the program because the error occurs in a remark statement, which isn't executed by BASIC.*

In addition, here are some tips that may eliminate the problems caused by terms in the program that aren't recognized by some versions of BASIC.

DEF FN LESS(X) *in line 190 converts any angle into an equivalent angle between 0° and 360°. This function is used in lines 430, 460, and 490, when the computer evaluates this function for the specified variable. You can obtain the same results if you delete line 190 and change the other three lines so the function is evaluated individually at each line. For example, line 430 could be changed to read* SM=((SM/360)−FIX(SM/360))*360.

FIX *pops up in lines 190, 310, and later lines. It omits all digits after the decimal point so only the integer before the decimal remains.* FIX(X) *is equivalent to* SGN(X)*INT(ABS(X)), *so line 310, for example, could be changed to* K3=ABS(K−SGN(K)*INT(ABS(K))).

The % *used after certain variable names and numbers, as in line 200, tells the computer to treat the value strictly as an integer. This saves memory and execution time, but the symbol doesn't have to be used: the* % *signs can be eliminated without affecting the results of the program.*

After certain constants in the program the # symbol is our computer's way of marking numerical values that have more than six significant figures. If the program bombs with this symbol, just leave out the # symbols that appear after numerical constants and enter as many digits of the number as your BASIC can deal with.

The E *used in lines 420, 450, 480, 540, 580, and 2730 signifies exponential notation, which tells the computer that the number immediately before the* E *should be multiplied by 10 to the power after the* E. *As an example, line 420 uses* −3.47E−06. *This number can also be entered as* −3.47*10^6 *or* −.00000347 *and will produce the same result in most BASICs.*

The PRINT USING *statements used after line 1940 make your printed copy look nice. If your machine can't handle this statement, eliminate the word* USING *and the hash marks that occur in those statements. The output won't be as nicely organized, but the correct information will still be printed. As an example, line 2080 could be changed to* PRINT "Moon Enters Penumbra";TI%(1);":";TI%(0);"ET".

Rocket Spectacle Explained

Sir / In "Japanese Rocket Causes August Light Spectacular" (AstroNews, December 1986), you reported that sightings of the rocket were made from as far west as Louisiana, but I spotted the rocket from central Texas.

My family and I were camping in Cold Springs, Texas, near Garner State Park. While viewing the Perseid meteor shower, I observed the rocket at 9:10 p.m. about 20° above the horizon and blazing at about magnitude 0.8. I kept the rocket sighted for ten to twelve minutes before it finally disappeared into a cloud.

When I saw your article I was pleased to finally find an explanation for my sighting and thrilled to have witnessed such a chance event.

Max L. Hennig
Tuleta, TX

Catching the Geminids

Sir / I watched the Geminid meteor shower on the morning of December 14. It was a frigid 0° F but the wind was calm. While a friend kindled a small fire in his barbecue, I began the watch. A very large Moon was still an hour away from setting, but despite this we were able to collectively spot sixty meteors in about one and a half hours. The brightest streak was about magnitude −2.

The shower was a rewarding experience. I only wish there had been more people watching with us. We probably saw less than half of the meteors that were visible because of the glare of the Moon and frequent trips to the fire to warm our bodies.

Thanks for "The Quadrantids: Bright Prospects for 1987" by Philip M. Bagnall (Gazer's Gazette, January 1987). Another meteor shower to watch!

Thomas F. Rankin
Highland, NY

A Salute to Galileo

Sir / The details of the Galileo mission in "Return to Jupiter" by Gary Bennett

(January 1987) bring up an interesting and exciting possibility. The Galileo launch is scheduled for November 1989 and, after a swing past Venus, it will pass by Earth in December 1990 at a distance of approximately 2,236 miles. The craft is scheduled to again pass Earth in December 1992 at a distance of only 190 miles or so.

If the closest approach occurs near the morning or evening terminator of Earth, many observers might be able to see Galileo appearing as a very fast moving satellite. The craft will be moving at 14.1 kilometers per second compared to the Earth's orbital speed of 4.8 miles per second, so the craft could be followed with ease.

Galileo will not have been seen since launch three years before; giving it a friendly wave as it sails off forever to be locked in the gravitational embrace of the "King of Planets" might be a nice tribute.

Bill R. Smith
Ukiah, CA

Mount Wilson's Recent History

Sir / In "Reach for the Stars: The Story of Mount Wilson Observatory" by Joseph M. Horodyski (December 1986), the author briefly mentioned that the 100-inch Hooker telescope was used for spectroscopic research in its last days. I thought your readers would be interested in the details of that research.

From 1981 until 1985 at least one-third of available time on the 100-inch telescope was devoted to a survey of stars in the "halo" of the Milky Way. Conducted by Allan Sandage of the Mount Wilson and Las Campanas Observatories and his assistant Gary Fouts, this long-range study program attempted to achieve a better understanding of the origin and structure of our galaxy.

First, a Shectman Reticon spectrometer attached to the 100-inch telescope's coude spectrograph was used to obtain spectra of a large sample of subdwarfs — the oldest known galactic stars. The radial velocity of each star was combined with the star's photometric parallax, proper motion, and position in the sky to determine the star's individual space-motion vectors.

From analysis of the stellar spectra and photometric data, the metal content of these halo stars could be determined and may provide clues about how the Galaxy formed.

Another ongoing observing program was being performed by a husband-and-wife team of astronomers, R. and R. Griffin, who were based at Cambridge Observatories in England. The Griffins used the coude spectrograph for several pioneering studies in stellar spectroscopy. Their work included untangling the spectra of hard-to-detect spectroscopic binaries and producing highly detailed "atlases" of the spectra of Betelgeuse and several other stars.

A project involving the search for planets around nearby stars was also under way. Geoff Marcy, a staff astronomer at San Francisco State University, used the coude spectrograph to study a number of subdwarfs in the solar neighborhood. He was looking for periodic changes in the radial velocity of subdwarfs that would indicate the presence of relatively massive planetary companions.

At the time it was closed, the Hooker 100-inch telescope was an extremely useful instrument for research that didn't require a particularly dark background sky, especially for projects involving stellar spectroscopy. Because it couldn't be used for distant galactic observing meant that the telescope was available for long-term studies of the nature of our galactic neighborhood — studies virtually impossible to perform on other large telescopes because of time constraints.

Robert L. Eklund
Mount Wilson Observatory Association
Pasadena, CA

Oops!

Two photos in recent issues were inadvertently reversed left for right. In the photo of the crescent Moon at the top of page 58 in the January 1987 issue, the cusps of the Moon should point to the right, and the sunrise glow should appear on the left side of the photo.

On page 61 of the February issue the shadow of the rings in the photo of Saturn should appear on the right side of the globe to reflect the description given in the article.

Behind the Scenes

April Is the Cruelest Month . . .

If the winter doldrums have kept you indoors, April is a fine month for getting active again. If you'd like something big, mysterious, and distant to observe, try finding 3C 273 in Virgo with this month's Gazer's Gazette. It's a quasar bright enough to find in backyard telescopes 8 inches and larger. Of course it doesn't *look* very impressive in the eyepiece, but the thrill comes from the act of finding the object and knowing that the light you're seeing is far older than humankind's most ancient history.

As a cure for the "astrophotography's-too-(expensive, complicated, technical, etc.)-for-me-to-get-into" syndrome, we're recommending piggyback astrophotography. If you have a camera and a telescope, this month's Photography in Astronomy shows how you can get started in one of the most satisfying branches of hobby astronomy. For the price of a couple of rolls of film and a few nights of guiding, you'll have the stars at your fingertips. Don't worry if your initial results aren't esthetically pleasing — that will come with practice.

Recently I've been looking for hubcaps every time I stop for gas at a truck stop. This sounds odd, but a hubcap is an essential part of a do-it-yourself all-sky camera in this month's Equipment Atlas. Just any old hubcap won't do. When I find the kind I'm looking for — a 13-inch "Baby Moon" — I'll buy it and build myself an all-sky camera, complete with a built-in heater for keeping off the dew. It's a project I'm really looking forward to.

One of ASTRONOMY's regular writers has done it again: David Levy recently discovered another comet. (David co-authored our feature article, "Betelgeuse.") Because he discovered his first comet while talking on the telephone (and observing with his 16-inch Dobsonian telescope), I asked what he'd been up to this time. It turns out that on January 5 at 5 a.m. he'd just finished writing a draft of the last chapter of his forthcoming book on observing variable stars and had put his word processor to work printing out a copy. Looking out, David noticed the sky had cleared while he had been writing, so he went outside for forty-five minutes of predawn comet hunting — and found what is now known as Comet Levy (1987a). It's a dim comet moving away from the Sun, which makes him doubly proud because it wasn't an easy find. Congratulations, David.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

SUPER POLARIS C8
(Shown with optional 8 x 50 finder)

Celestron's SUPER POLARIS C8

List:
$1,750

OUR PRICE:
$ 849

The SUPER POLARIS C8 is still your best dollar-value in a full-featured, significant-aperture astronomical telescope. Complete kit includes 8in Schmidt-Cassegrain Telescope, German-type Equatorial Mount, and adjustable Tripod. Complete listing of features and factory-specified equipment included with each telescope is as follows:

8in Aperture, 2000mm Focal Length (f/10 Focal Ratio) telescope tube assembly, with Celestron's world famous, hand corrected, diffraction limited, laser tested, individually certified optics; Widefield 6x30mm straight-thru finderscope; 26mm (77x), 1.25in barrel, multi-coated, premium grade Plossl eyepiece; High brightness, mirror type 1.25in star diagonal; 1.25in visual back; Piggyback camera mount; Hand strap for holding scope tube during setup & takedown; Quick-mount slider bracket for mounting and balancing scope tube; Dust caps; High-tech black finish on scope tube; Lockable foam-lined carrying case for scope tube; Starwatch by Ben Mayer; Subscription to Deepsky magazine; German-type equatorial mount with: Full 360x worm-drive "slow motion" controls (with anti-backlash adjustments), setting circles, and vernier brakes on both axes of motion (also includes mounting provision for optional pulse-motor drive on each axis); Micrometer latitude adjustment (0-90Deg!), with latitude scale; Micrometer azimuth adjustment; Bubble level; Built-in (polar-axis) illuminated-reticle polar alignment telescope; Sliding-type counterweights (for quick adjustment) on quick-disconnect counterweight shaft (for quick setup & takedown); Adjustable scope tube mount (for quick balancing); High-damping, adjustable wood tripod; Accessory tray; High-tech black & silver finish on metal parts.

Ask about optional Optical Coatings & Electronic Drives!

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OUR PRICE:
$1695

Celestron's newest incarnation of their classic fork-mounted 8in Schmidt-Cassegrain is so advanced that it is ONLY offered with built-in QUARTZ microelectronic drive corrector (Hand Control Unit included!) and STARBRIGHT optical coatings. AC or DC, N or S hemisphere operation out of the box, it makes all earlier fork-mounted C8's obsolete. Features and factory-specified equipment are as follows:

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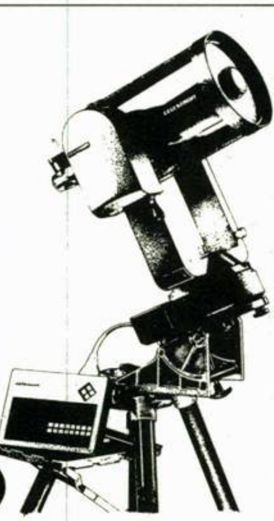
Ask about optional Declination and Focusing Motors!



Celestron's COMPUTER CONTROLLED TELESCOPES

Perhaps the most revolutionary advance in commercially-made telescopes since Celestron introduced the Schmidt-Cassegrain telescope itself, fifteen years ago, Celestron's new computer controlled, fork-mounted CCC8, CCC11 and CCC14 are the most awesomely powerful instruments available to the amateur astronomer today! The enormous power and flexibility of the Celestron CCT microcomputer puts these instruments into a class by themselves, with capabilities matched only by advanced research-grade instruments. With coordinates and data on over 8,000 astronomical objects stored in its memory, and slew speeds of up to 15 degrees per second, the computer's full listing of features and capabilities is too extensive to itemize here. Please write or call for additional information, pricing and delivery estimates.

Description	List	You Pay
CCC8, StarBright, Wedge, Tripod	$ 6,530.00	**$ 3,895.00**
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CCC14, StarBright, Wedge, Tripod	21,570.00	**Call**

NOTE: We specialize in retrofit "computerization" of existing privately and institutionally-owned C11's and C14's. Please contact us regarding the upgrading of your existing telescope. Production rates are limited.

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Gaining Confidence with Piggyback Astrophotography

Photography in Astronomy

by Rick Dilsizian

You've just spent forty minutes outside enduring mosquitoes, a strained neck, and severe eyestrain to take your first astrophoto. Anxiously you process the negative. Nervously you remove it from the fixing bath. But hope turns to disappointment when you examine the negative. There are doughnuts where stars should be and a smudge where nebulosity should be. Disappointment turns to anger and disgust while you ask yourself: "Did I just spend $1,000 on astrophoto accessories to get a shot like this?"

If this has happened to you, you're not alone. More people have experienced the frustrations of astrophotography than the pleasures. Perhaps those who succumbed to their frustration and gave up, gave up too soon.

Astrophotography, like any art, is a learning process. You build on experience and gain confidence with small victories. You don't paint a Mona Lisa when you just take up oil painting; similarly, you can't expect to successfully photograph the Ring Nebula in Lyra the night after you receive your new telescope. You still need to learn the fundamentals of tracking, polar alignment, and focusing.

Where do you begin? With piggybacking, one of the easiest techniques of astrophotography. As its name implies, piggybacking involves mounting a camera on a telescope to make time exposures of the night sky. The telescope is used for guiding, and the camera, attached to the telescope, tags along. You can use wide-angle, normal, or telephoto lenses, depending on the amount of sky you want to record. Piggybacking is a step up from tripod astrophotography and allows you to capture fainter stars and many deep-sky objects.

Guiding Tolerances

One of the biggest advantages of piggybacking is that you don't have to guide as accurately as you do when photographing through your telescope. Remember that tracking accuracy is proportional to focal length, so a longer focal length instrument requires greater tracking precision than one with a shorter focal length because the first type covers such a small area of sky, usually not more than a degree or two.

The Andromeda Galaxy, shot with a 200mm lens at f/2.8, Tech Pan 2415 film, and a 10-minute exposure. Photo by A. W. Steinbrecher.

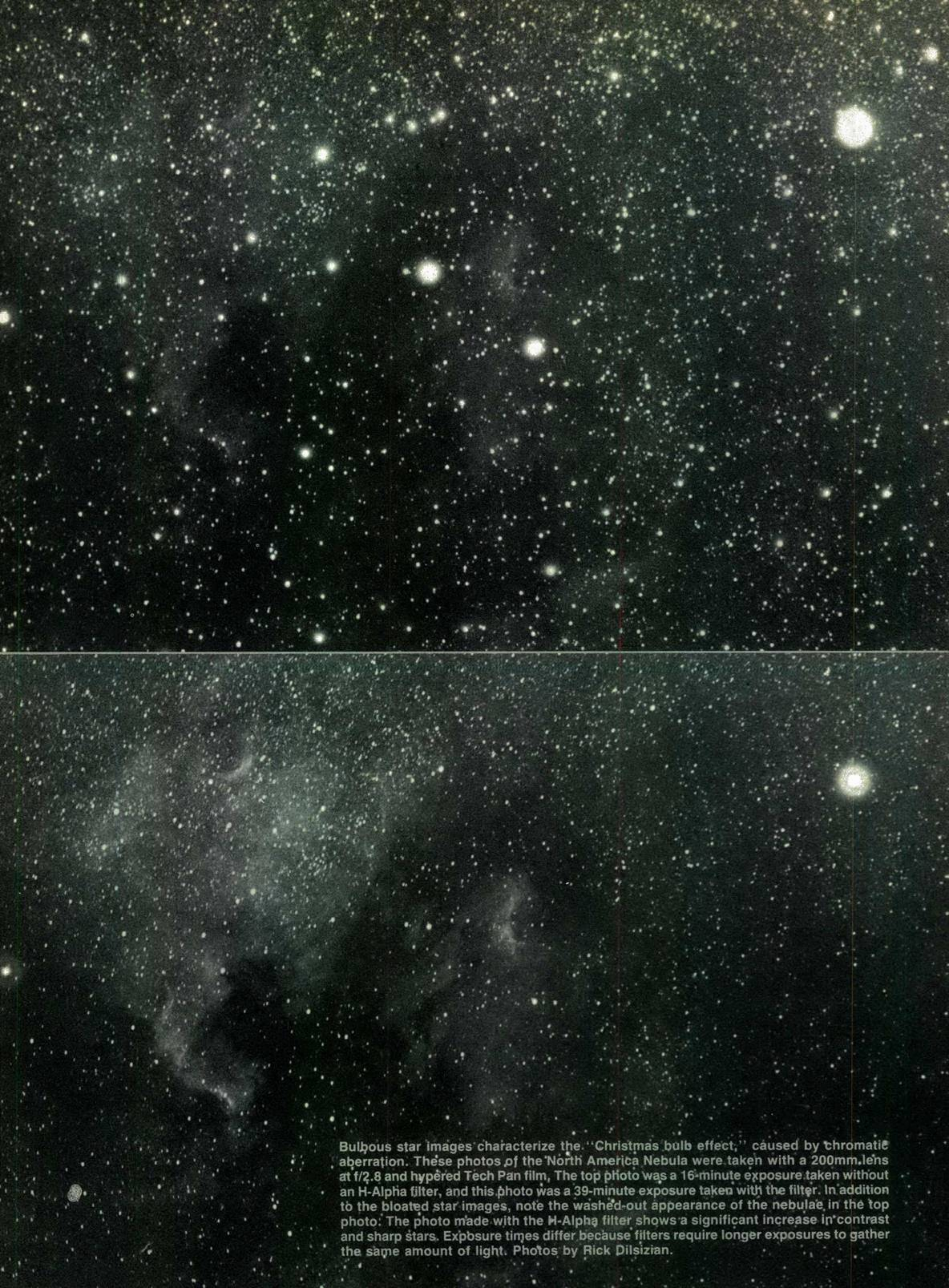
For example, when you use a Schmidt-Cassegrain with a focal length of 2,000 millimeters, you cannot make a guiding error of more than about 4 arcseconds or your stars will appear trailed (although some would argue that even 4 arcseconds is too much!). However, the field of view of a 28mm wide-angle lens is about 46° by 65°. In this case you can afford a maximum guiding error of about 290 arcseconds. For a normal 50mm lens covering a field approximately 27° by 40°, your maximum guiding error is about 165 arcseconds. And for a 200mm telephoto, which covers a field of view of 6.8° by 10.3°, your guiding tolerance is a little over 42 arcseconds. This means that a telephoto lens needs only 1/10th the accuracy of a 2,000-millimeter focal-length Schmidt-Cassegrain, a normal lens requires 1/40th the accuracy, and a wide angle lens requires 1/71st the tracking accuracy. (For more information on guiding tolerances, see "Guiding Magnifications for Top-Quality Astrophotos" in the October 1986 issue.)

Although the more forgiving nature of these lenses is no reason to avoid tracking to finer tolerances, these lenses do allow you to make mistakes without getting the discouraging results that photographing through a telescope would produce. The net difference to you is that the stars will appear as dots and not as trails, and more and more of your astrophotos will be worth keeping as you improve your guiding.

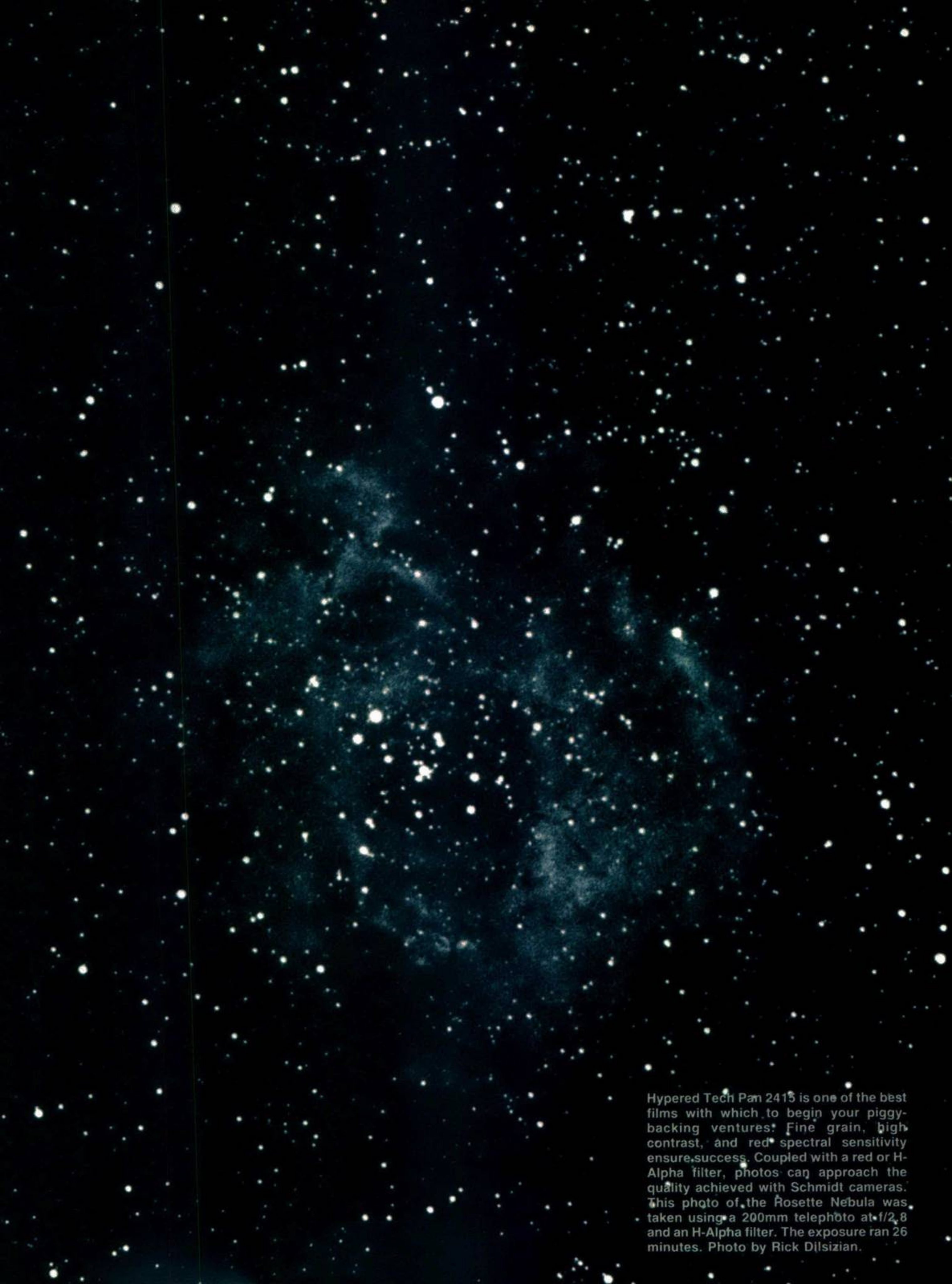
Another advantage of piggyback astrophotography over telescopic photography is the greater selection of guide stars at your disposal. When photographing through the telescope, you have to track on a guide star through either a guidescope mounted on the side of the telescope or an off-axis guider. In both cases the area in which to search for a guide star is limited because the photographic field of view is a degree or two at most. You usually begin by centering the camera's field of view on the object you want to photograph and then search for a guide star within or just outside the field. Hopefully the star you select is bright enough to track but not too far from your object.

Finding a guide star is easy for piggyback work because your camera covers a larger area of sky, perhaps fifty to three thousand times greater than that covered by the telescope. Within that area you should have no trouble finding a bright star on which to guide. And you can find your guide star first and then compose your astrophoto in the camera accordingly.

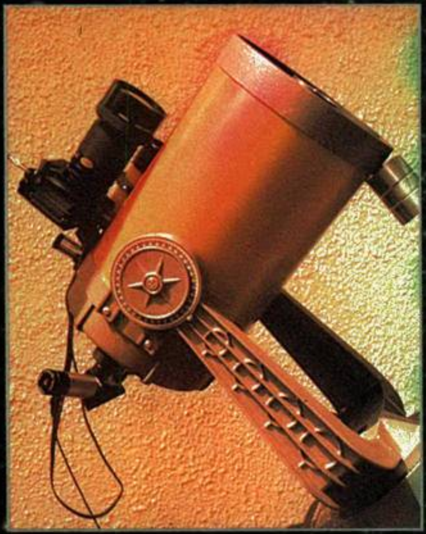
Finally, the wide-angle and normal camera lenses mentioned above can produce sweeping panoramas of the sky. Whole constellations bloom with bright nebulae and clouds of stars; the Milky Way becomes a bright band of stars interspersed with dark nebulae. Piggybacking takes in large sections of sky and reveals details that lie just beyond what



Bulbous star images characterize the "Christmas bulb effect," caused by chromatic aberration. These photos of the North America Nebula were taken with a 200mm lens at f/2.8 and hypered Tech Pan film, The top photo was a 16-minute exposure taken without an H-Alpha filter, and this photo was a 39-minute exposure taken with the filter. In addition to the bloated star images, note the washed-out appearance of the nebulae in the top photo. The photo made with the H-Alpha filter shows a significant increase in contrast and sharp stars. Exposure times differ because filters require longer exposures to gather the same amount of light. Photos by Rick Dilsizian.

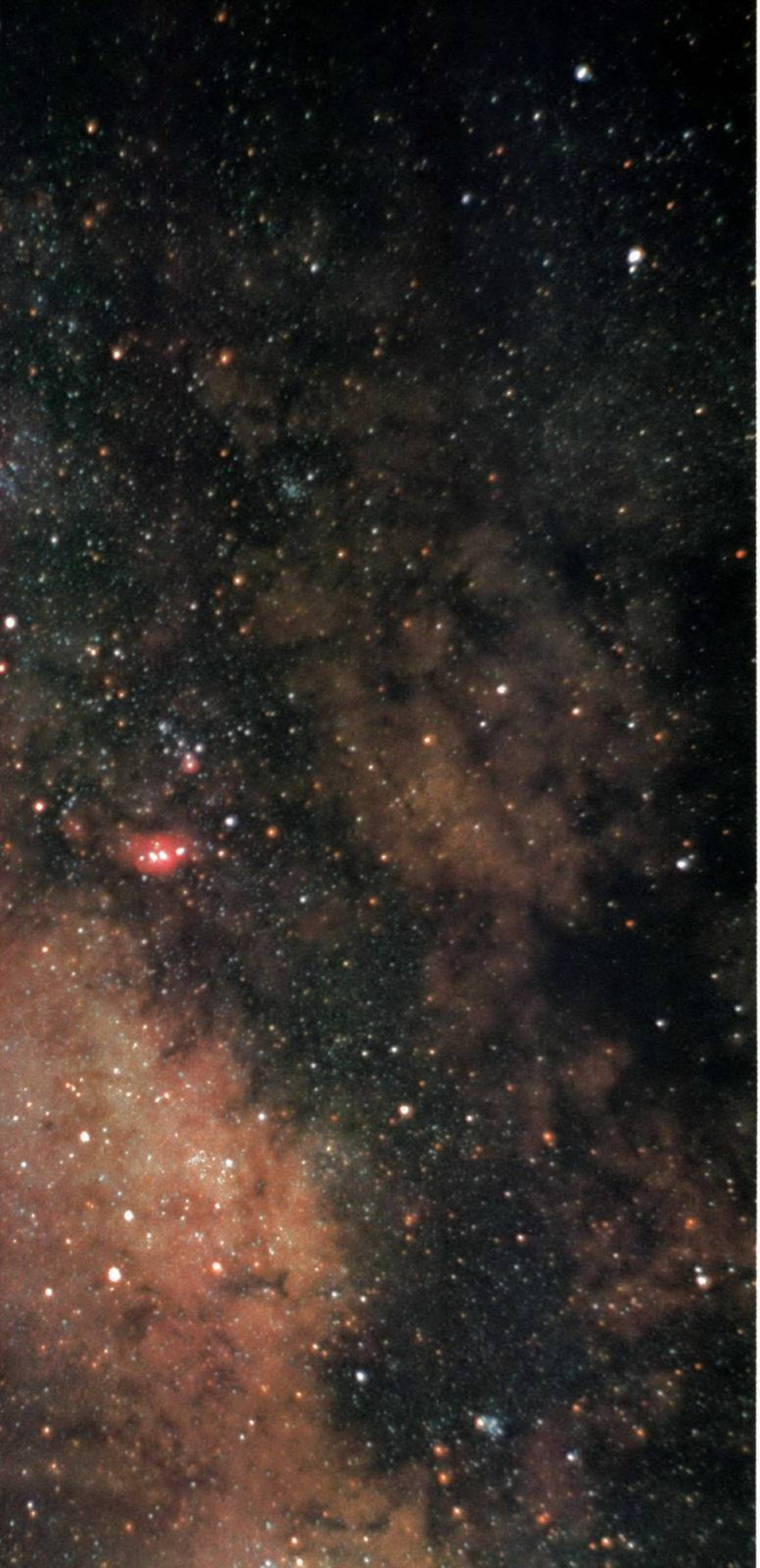


Hypered Tech Pan 2415 is one of the best films with which to begin your piggybacking ventures. Fine grain, high contrast, and red spectral sensitivity ensure success. Coupled with a red or H-Alpha filter, photos can approach the quality achieved with Schmidt cameras. This photo of the Rosette Nebula was taken using a 200mm telephoto at f/2.8 and an H-Alpha filter. The exposure ran 26 minutes. Photo by Rick Dilsizian.



Above: This is a typical piggyback setup for a Schmidt-Cassegrain telescope. Note the counterweights hanging from the front of the tube. The addition of a camera will probably require you to rebalance your instrument. Be sure to mount the camera so that the upper portion of the telescope tube is out of the photographic field. Photo by Rick Dilsizian.

Sagittarius, with its many star clouds, clusters, and nebulae, is a rich region for piggyback astrophotography. The bright "star" in the center of the photo is Jupiter. Richard Soikkeli made this half-hour exposure using a 50mm lens at f/2, without a filter, and Fugi 100 film. (This was Soikkeli's first attempt at astrophotography.)



our unaided eyes can see.

The major disadvantage of piggybacking has already been mentioned as an advantage! Because piggyback work involves lenses with shorter focal lengths and covers large areas of sky, deep-sky objects with small angular diameters are just tiny specks on the negatives. Forget about photographing objects like the Ring Nebula, the Dumbbell, or some of the smaller, fainter galaxies and globular clusters. Forget about close-ups of the Moon and planets as well. Planets appear as bright "stars" and the Moon is a dot of light, although its phase is distinguishable in shots made with most telephoto lenses. However, a number of sky objects record quite well with this method, and some of these are listed on page 45.

Steps toward Perfect Piggybacking

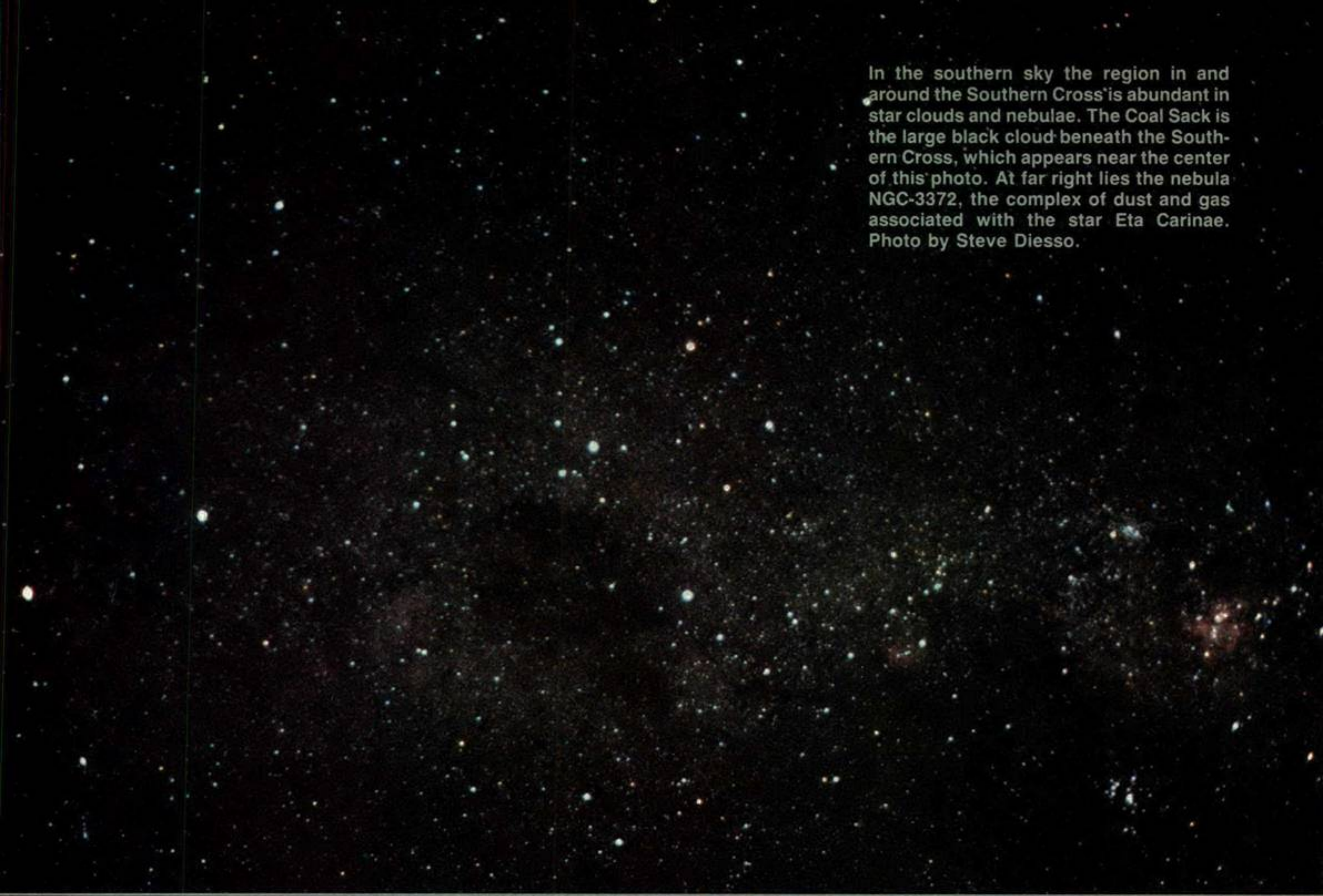
Besides the obvious necessities of a telescope, drive corrector, and camera, you will need the following equipment for piggyback astrophotography:

- A piggyback attachment that couples your camera to your telescope's tube.
- A cable release, preferably with a locking mechanism for time exposures that can be set and released with one hand. Any local photo store should carry them.
- A lens hood to prevent stray light from entering the camera lens.
- A guiding eyepiece with either a single or dual set of cross hairs, preferably illuminated. As with telescopic astrophotography, the higher the power of the guiding eyepiece, the more accurate your tracking will be. However, 50x to 75x is quite often sufficient for piggybacking because, as mentioned before, the larger field of view can tolerate greater tracking error.
- Extra counterweights to balance your telescope when the camera is attached. These can be obtained from telescope manufacturers or you can devise your own (barbell weights work effectively). For Newtonian telescopes the camera is normally mounted over the cradle rings, in which case additional weight need only be applied to the declination axis.

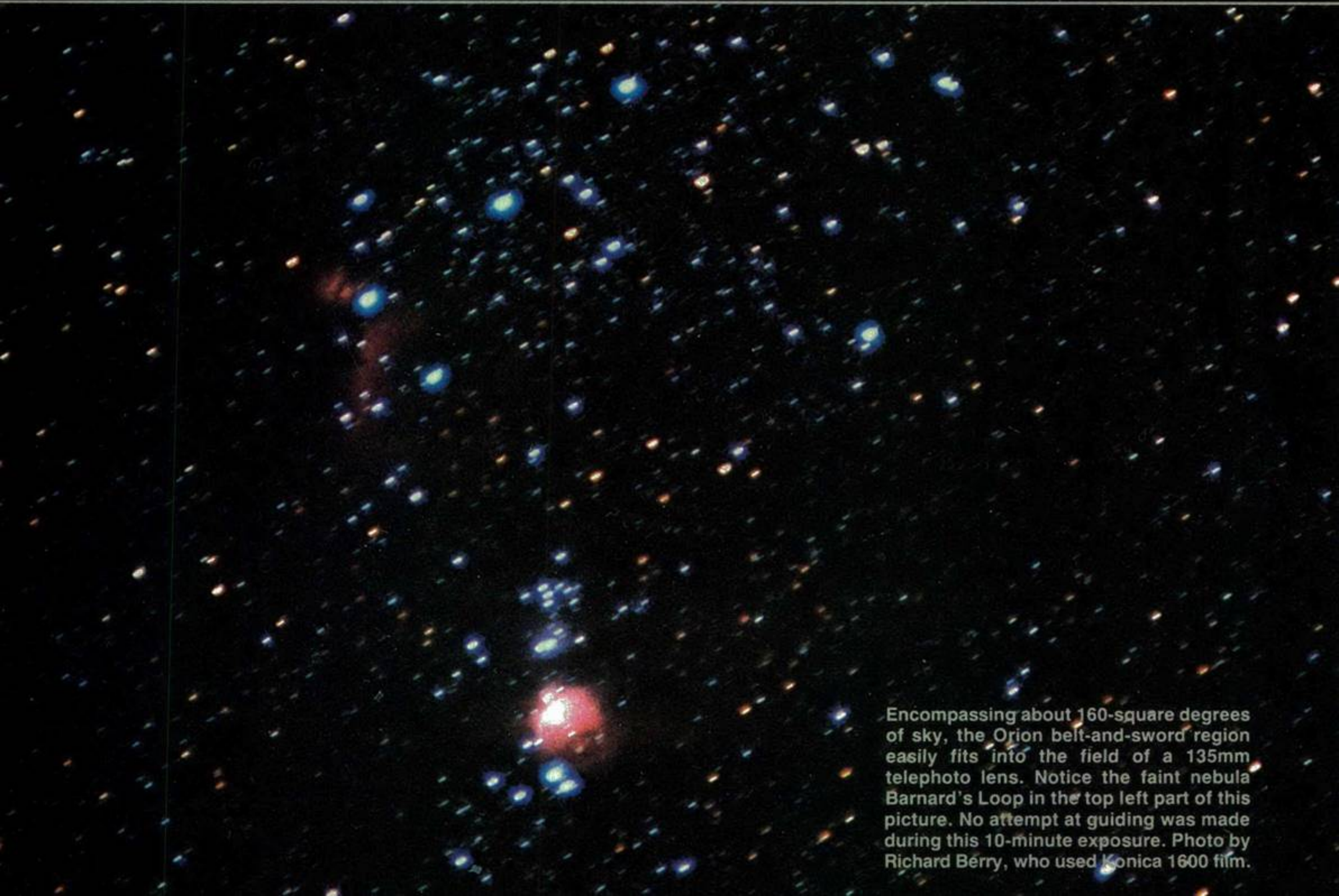
To take a piggyback astrophoto, follow these simple steps.

Step 1: Attach your camera (already loaded with film) to your telescope with the piggyback attachment. Do this during daylight so you don't have to fumble around in the dark. Make sure the camera mount is secure: you don't want your camera to fall or shift in the middle of a 40-minute exposure.

Step 2: Attach the cable release and lens hood (also best done during daylight) and set the lens opening one stop below maximum to prevent lens distortion toward the edge of the frame. Set your shutter on "B" (bulb) for indefinite time exposure and set your lens focus on infinity. (You may need to refocus slightly to get precise stellar points.)



In the southern sky the region in and around the Southern Cross is abundant in star clouds and nebulae. The Coal Sack is the large black cloud beneath the Southern Cross, which appears near the center of this photo. At far right lies the nebula NGC-3372, the complex of dust and gas associated with the star Eta Carinae. Photo by Steve Diesso.



Encompassing about 160-square degrees of sky, the Orion belt-and-sword region easily fits into the field of a 135mm telephoto lens. Notice the faint nebula Barnard's Loop in the top left part of this picture. No attempt at guiding was made during this 10-minute exposure. Photo by Richard Berry, who used Konica 1600 film.

Step 3: While there is still light, go outside and set your telescope so the polar axis faces north (or south for those in the Southern Hemisphere) and points at the approximate altitude of the celestial pole.

Step 4: Once it is dark enough to see the pole star, properly align your telescope's polar axis on the celestial pole. This procedure can get involved to the point of distraction, but for piggyback astrophotography you need only be within a quarter of a degree or so of the true pole, especially if you have a dual-axis drive corrector. (Single-axis correctors, though, must be aligned precisely on the celestial pole to prevent a gradual drift in declination.)

With your telescope parallel to its polar axis, shift the entire mount (*not the equatorial setting*) so the center of the field of view is slightly less than one degree away from Polaris in the direction of the last star in the handle of the Big Dipper. In the Southern Hemisphere shift the mount so the telescope's field of view is centered roughly one degree from the 5.5-magnitude star Sigma (σ) Octantis in the direction of Beta (β) Carinae (Miaplacidus). In both cases you may have to adjust the altitude of your polar axis slightly.

Step 5: Point the telescope at the area of the sky you wish to photograph. Find a bright guide star in this area and center it in your guiding eyepiece. Check the guide star in the eyepiece to ensure your clock drive is tracking well. Focus the camera on a bright star in the matte area surrounding the central split-image window (unless, of course, your camera is equipped with a clear screen). Now slowly depress the cable release. Make sure the locking mechanism on the cable release engages. After all, how would you feel if you made a 50-minute exposure and then discovered that the locking mechanism never locked and you only got 2 seconds worth of exposure?

Step 6: Guide the telescope and end the exposure whenever you please. At the end of the exposure cover the lens with your hand or a black piece of cardboard to avoid recording jiggled stars when the camera's shutter slaps shut, and then release the locking mechanism on your cable. Advance the film and make another photograph!

Film and Exposure

If you are a beginning astrophotographer, here's some advice on the types of films that are best for piggybacking. For black-and-white work the best film is Kodak's Technical Pan 2415, preferably hypersensitized. Tech Pan is a fine-grain, fast (when hypered), high-contrast film. Moreover, the spectral sensitivity of Tech Pan — sensitized to wavelengths well into the red end of the spectrum — makes it good for use in moderately light-polluted skies. The merits of Tech Pan film, however, should not preclude your experimenting with Tri-X or any of the other conventional high-speed black-and-white films, especially if you're already using these films for ordinary photography.

SUGGESTED LENSES FOR ASTROPHOTOGRAPHY

Objects	Lens to Use
The Milky Way	18mm to 28mm
Big and Little Dipper in one frame	18mm to 28mm
Sagittarius and Scutum Star Clouds	50mm
Cygnus	50mm
Orion	50mm
Cassiopeia	50mm
The Andromeda Galaxy	200mm
The Pleiades	200mm to 300mm
The Orion Nebula	135mm to 200mm
The Horsehead Nebula	135mm to 200mm
The North America Nebula	135mm to 300mm
The Double Cluster	70mm to 300mm
The California Nebula	200mm to 300mm
The Trifid and Lagoon nebulae	200mm
The Rosette Nebula	200mm
The Veil Nebula (both components)	200mm
Large open clusters, globular clusters, and galaxies	200mm to 300mm

EXPOSURE TIMES USING TECH PAN FILM

If the f/ratio is:	Exposure for nebula or galaxy:	Exposure for open or globular cluster:
f/1.4	5-10 minutes	3-5 minutes
f/2	10-15 minutes	6-10 minutes
f/2.8	20-30 minutes	12-20 minutes
f/3.5	30-45 minutes	18-30 minutes
f/4	40-60 minutes	24-40 minutes

You can also use color slide film. Several types are very good for piggyback astrophotography: Fujichrome RD100, Fujichrome RH400, Ektachrome 200 and 400, and 3M 1000 film. The best color print film currently available is Konica 1600 because it's very sensitive and generally gives excellent color rendition of both stars and nebulae. As with all print films, the quality of the result depends on your photo finisher, so find a good one!

Exposure times depend entirely on the film you use, the lens and f/stop you select, and sky conditions. Because these factors are variable, experiment to determine exposure times, especially since many pictures are not taken from dark sky sites and are often subject to sky fog and varying atmospheric conditions.

The film you select and the specifications of your camera will probably have the most influence on how long you decide to expose. As an example, ISO 200 film and a 50mm lens at f/2 will record 10th-magnitude stars in about 5 minutes. On the other hand, adequately recording the Milky Way using the same lens and film could take an exposure of 30 minutes or more. You can cut this time in half, however, if you use film with a speed of ISO 400. As another example, if you get a shot of the constellation Cygnus in 20 minutes using ISO 100 film, you should get the same shot using ISO 400 in 5 minutes.

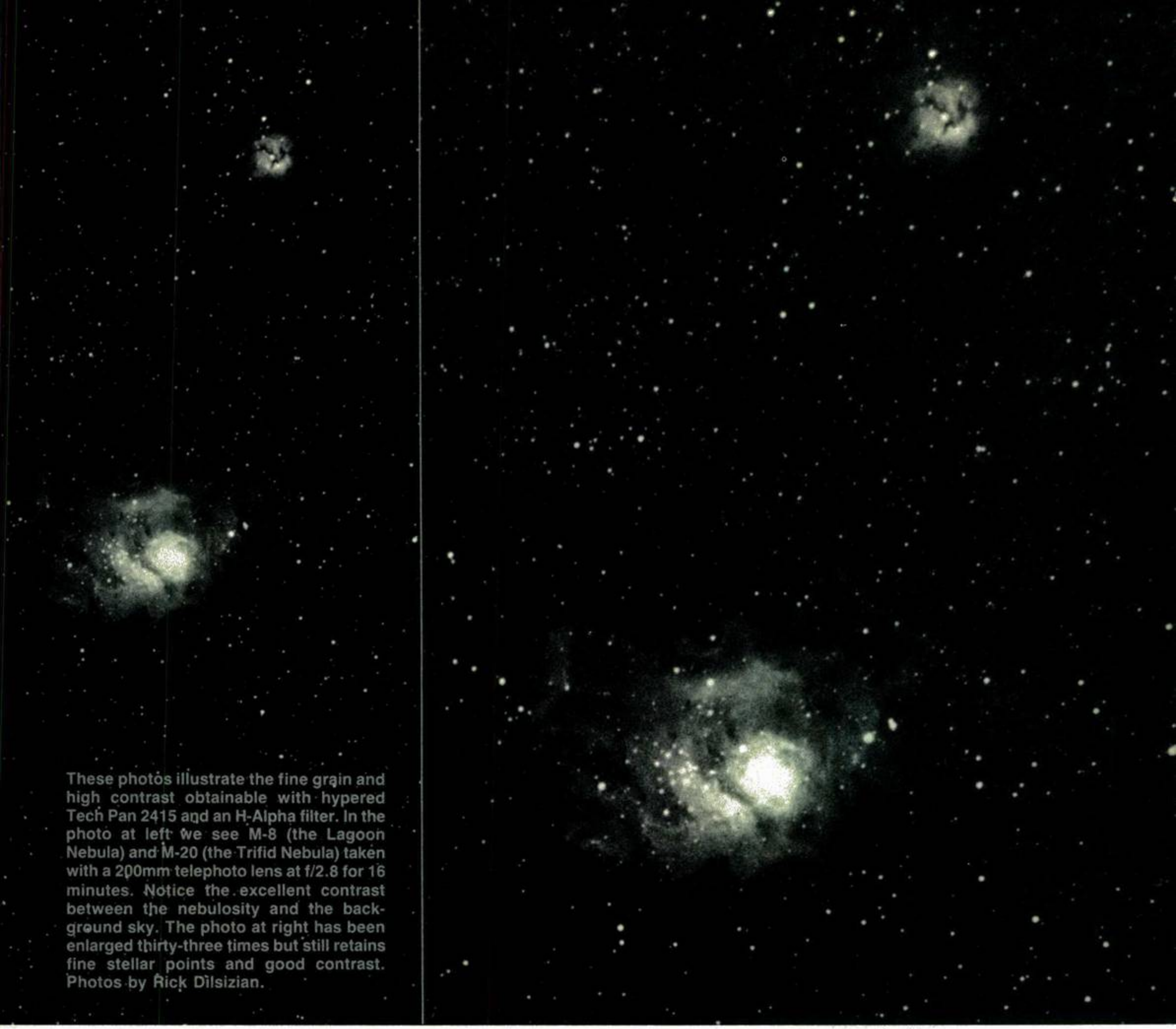
However, no matter how high the rated speed of a film, the film cannot integrate faint light indefinitely because of "reciprocity failure." This is the tendency of film to become insensitive to faint light during a long exposure. As a result, slow films sometimes are as "fast" for astrophotography as fast films.

For black-and-white piggyback astrophotography, the exposure table above should prove helpful.

"Christmas Bulb Effect"

Before you take your first sky photos, you may want to secure one other piece of camera equipment that will significantly enhance your astrophotos. Look at the two photos of the North America Nebula on page 40. In the top photo, a 16-minute exposure, the stars appear as blobs rather than pinpoints of light. I call this the "Christmas bulb effect." The lower photo, however, was taken the same night with the same lens and processed at the same time. In addition to sharper stars, the contrast is also better in the second photo. Why the dramatic difference?

The Christmas bulb effect is caused by residual chromatic aberration in the lens system. This means that different colors of light come to focus at different points passing through the lens. Hence, the focal point for blue light is often not the same



These photos illustrate the fine grain and high contrast obtainable with hypered Tech Pan 2415 and an H-Alpha filter. In the photo at left we see M-8 (the Lagoon Nebula) and M-20 (the Trifid Nebula) taken with a 200mm telephoto lens at f/2.8 for 16 minutes. Notice the excellent contrast between the nebulosity and the background sky. The photo at right has been enlarged thirty-three times but still retains fine stellar points and good contrast. Photos by Rick Dilsizian.

as that for red light, which is not the same as that for orange light, etc. So you end up with stars that look like Christmas bulbs instead of points.

The way around the effect is a red Wratten 25 or 29 filter, either glass or gelatin. Both are effective and readily available at camera shops. Another filter that works well is the Hydrogen-Alpha (H-Alpha) filter available from Lumicon. These filters work by transmitting only red light: blue, green, yellow, and violet wavelengths of light don't have a chance to fall on the lens and produce chromatic aberration. Only red light passes through, and the result is pinpoint stellar images and contrasty nebulosities.

There are, of course, limitations to filters. The first is that you must use filters only on objects that emit predominantly red light. Such objects are vast ionized hydrogen regions like the Orion Nebula, the Rosette Nebula, the North America Nebula, the Trifid Nebula, and the Lagoon Nebula, to name a few.

The second limitation is that, because conventional films are not sensitive to red light, you must use a red-sensitive film. Hypered Tech Pan or Kodak Spectroscopic films (103a-E and 103a-F) can do the job; Tri-X cannot.

The third limitation is that your exposures have to be longer if you shoot through a filter. Successful exposures made with filters are at least twice as long as exposures made without filters. For example, my exposure for the North America Nebula was 16 minutes without the filter and 39 minutes with it.

In addition, refocusing may be necessary. Exact focus is determined by making a few test exposures and noting your focus setting for each one. Use the focus setting that produces the sharpest test exposure.

These limitations are easy to deal with when you consider the results of using a red filter with a piggyback arrangement: sharper star images and a significant contrast gain, especially for faint nebulae. And because of its red spectral sensitivity, a red filter is ideal for suburban skies.

So don't ditch your camera! Look again at the advantages of piggyback astrophotography. Get a fast lens and a few rolls of film, mount the camera piggyback on your telescope, and start taking those photos. You'll have a system that produces pictures you can be proud of right from the start. Even more important, you will gain the confidence you need to progress to photographing through the telescope or improving your piggybacking technique. Your Mona Lisa awaits you!

Rick Dilsizian is an avid astrophotographer whose photos appear regularly in ASTRONOMY. By day he is a professor at Westchester Community College in Valhalla, New York. His most recent article, "Getting Started with a Schmidt Camera," appeared in the September 1985 issue.

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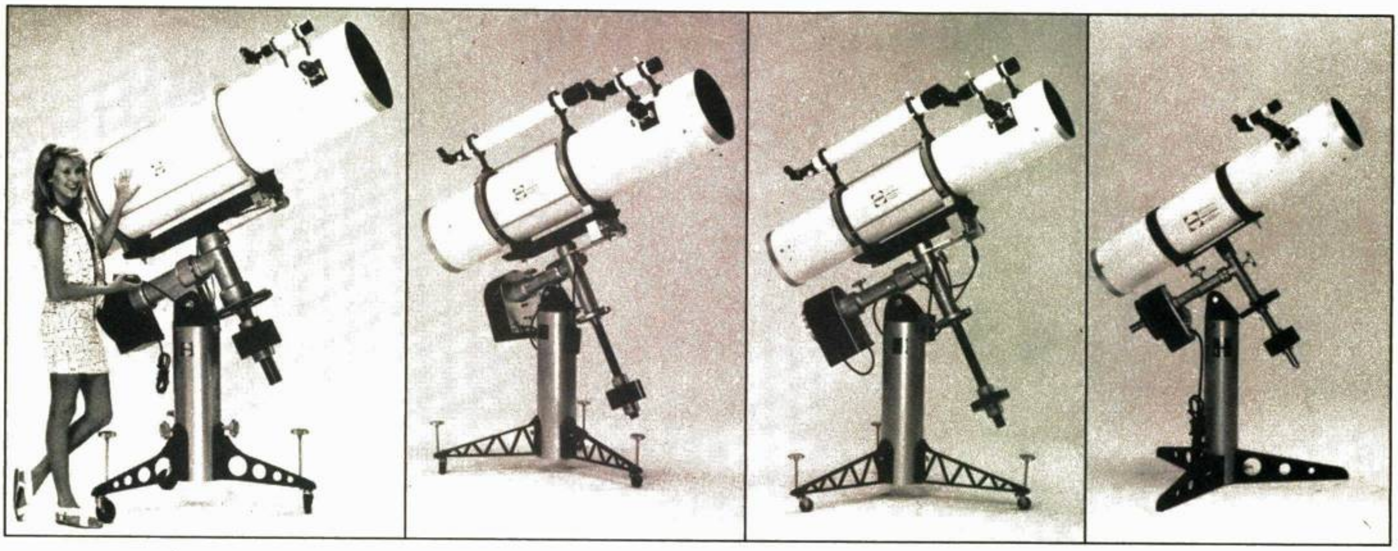

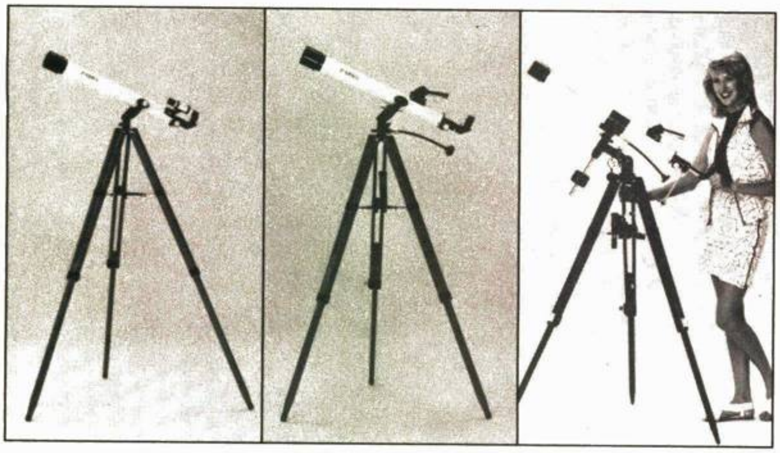

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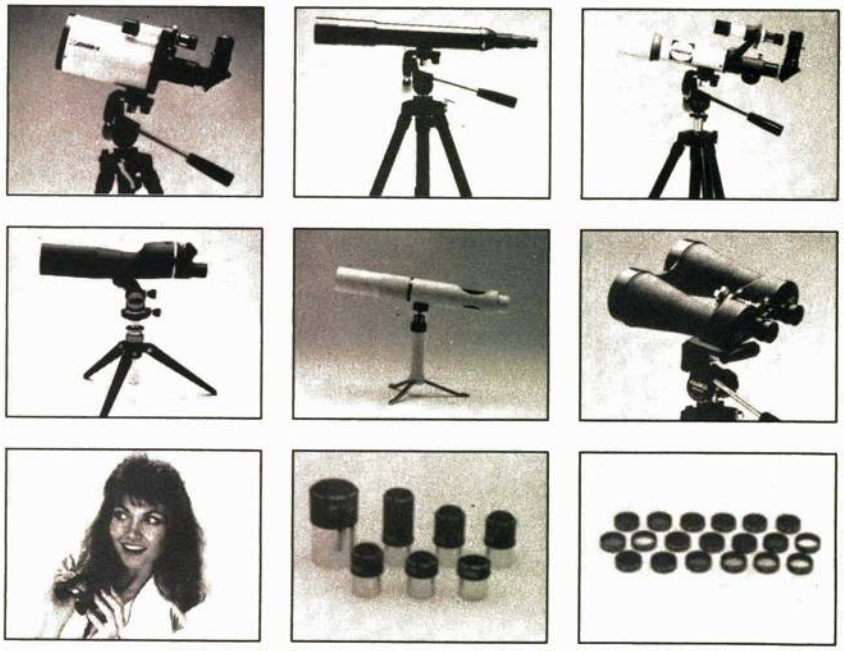

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Star Hopping to a Quasar

Gazer's Gazette

by John Mood

Quasi-stellar objects — quasars — are unquestionably the most intriguing objects in the universe. Although most quasars look like insignificant blue stars in large telescopes, each of these tiny points of light emits the energy of 100 or, in some cases, 10,000 normal galaxies. We don't see how truly bright quasars are, however, because they are so distant, extending nearly to the edge of the observable universe. Still, if quasars weren't so luminous we couldn't detect them at all.

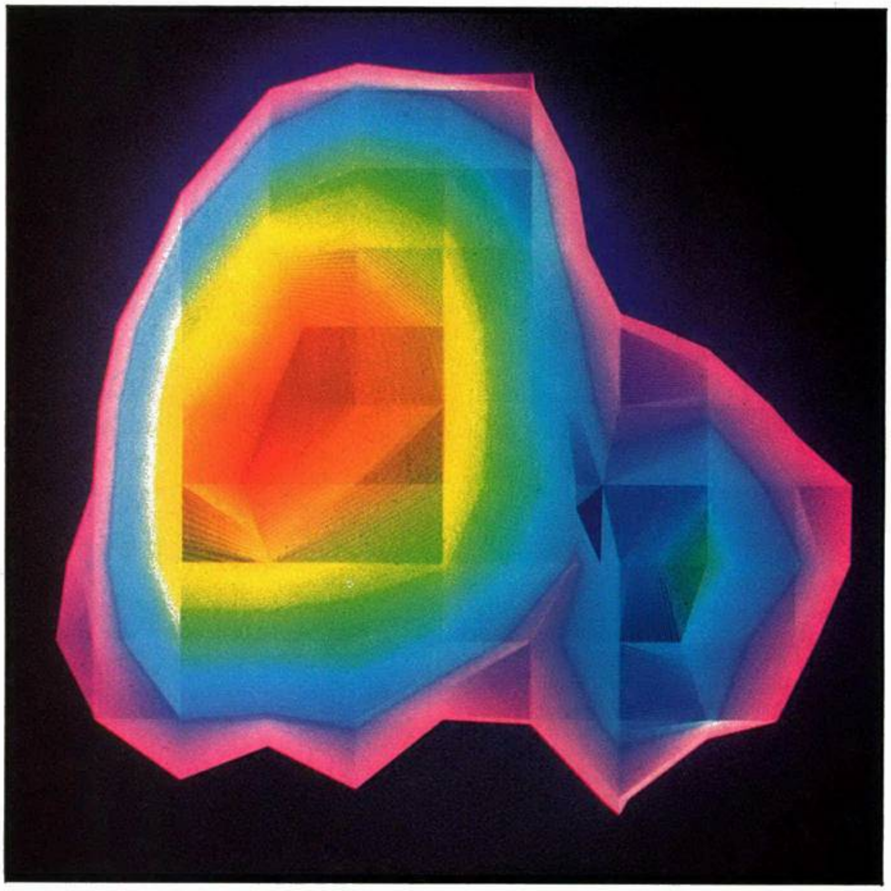
One might think, then, that quasars are detectable only in the largest telescopes aided by sophisticated electronic equipment, but actually several dozen are visible in 10- and 12-inch telescopes. The one with the brightest apparent magnitude is the nearest quasar, known as 3C 273 (from its designation in the *Third Cambridge Catalogue of Radio Sources*). The quasar is a 12.8-magnitude point of light in Virgo and easily within the range of an 8-inch telescope. In fact, an experienced observer on an excellent night of viewing might even spot it using a smaller instrument.

Although 3C 273 appears as a faint star, looking at its light — emitted when the earliest forms of life were evolving on this planet over 3 billion years ago — is nevertheless compelling. The photons from 3C 273 are older than any rocks on Earth. The quasar itself — like its more distant cousins — may no longer exist.

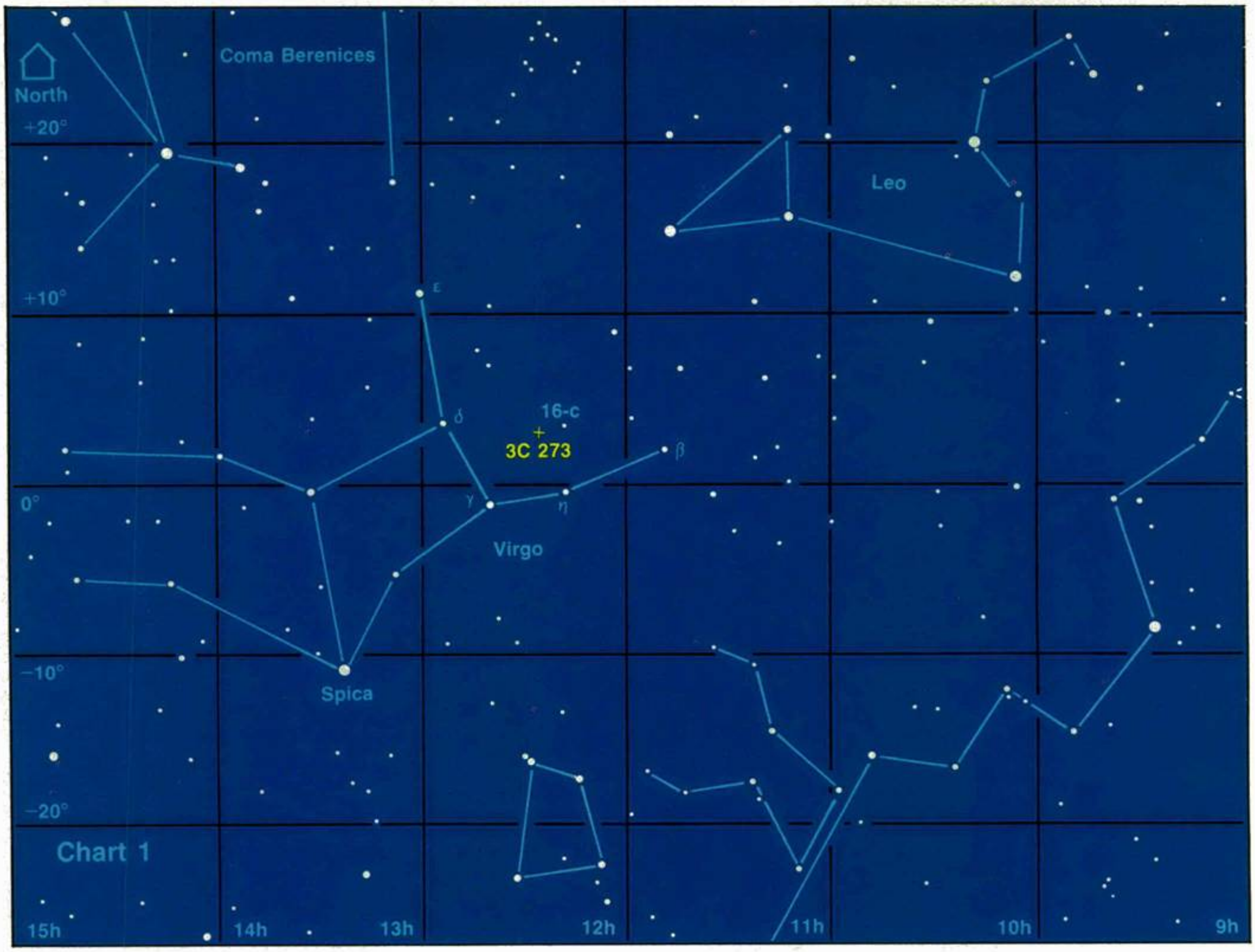
3C 273 also represents a significant piece of astronomical history. In 1962 astronomers at the Australian National Radio Observatory observed several lunar occultations of the radio source 3C 273. By precisely noting when the radio waves were blocked by the Moon, they were able to pinpoint the exact source of the radio emission. They were surprised to find that the optical counterpart of the strong radio source was a "star."

In fact, this was the second radio "star" to be pinpointed. (The first, 3C 48, was discovered in 1960 and had been considered just an odd star in our Galaxy.) The problem, astronomers realized, was that ordinary stars are not strong sources of radio emission. Yet here were two stars that seemed to emit radio waves that could be detected over galactic distances. For want of a better designation, astronomers dubbed these two objects "quasi-stellar radio sources," or QSRSs. In an effort to pronounce this acronym, the term quasars was coined. (Not all quasars emit strong radio waves, however. Those that don't are referred to as QSOs or quasi-stellar objects, though they're still considered quasars.)

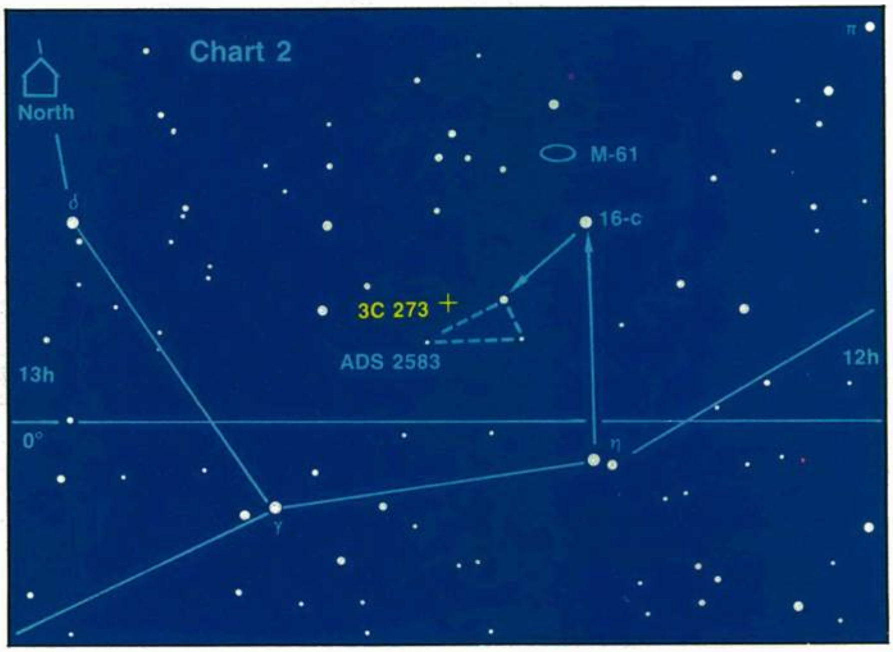
The spectra of these two radio stars were most strange: not a single recognizable emission line could be identified. Then in 1963 Maarten Schmidt at the California Institute of Technology realized that the brightest spectral lines of 3C 273 were positioned relative to the four familiar spectral lines of hydrogen, except that they were shifted 16 percent toward the red end of the spectrum. This meant 3C 273 was rushing away from Earth at a mind-boggling 16 percent of the speed of light



Powerful radio telescopes reveal a vastly different view of quasars than optical telescopes do. This ultra-high resolution image shows a knot of gas (lower right) jetting out from the core of 3C 273. Image courtesy of Jack Schendel.



These charts will enable you to star hop to the quasar 3C 273. Charts 1 and 2 are oriented with north at the top; Charts 3 and 4 have south at the top. Chart 1 shows the constellation Virgo, in which the quasar is located. Chart 2 is a 15° by 10° area in northwestern Virgo with the quasar's position shown north of the small triangle depicted in the center. Chart 3 is an enlargement of the region of the triangle in Chart 2. Look for 3C 273 in a smaller triangle of stars to the north of the larger triangle. Consider the two strings of stars indicated by the arrows as pointing toward the quasar. In Chart 4, zeroing in on the region further still, 3C 273 is indicated by the arrow at the bottom. It is the brighter of two stars on the northern edge of the smaller right triangle made up of five stars. All charts by John Mood.



(48,000 kilometers per second)!

Today more than three thousand quasars have been cataloged, all at even greater distances and surpassing the most remote galaxies. Surveys of small regions of the sky have found at least twenty quasars per square degree that are brighter than magnitude 20.

But how can something so far away be so bright? 3C 273 is 6 trillion times brighter than the Sun and 920 megaparsecs more distant. Even a mammoth elliptical galaxy would appear as only an 18th- or 19th-magnitude object at that distance. Moreover, 3C 273, like many other quasars, fluctuates erratically in brightness with periods as short as one year (these fluctuations are too slight to be detected by the eye). Because an object cannot change its brightness faster than the time light takes to travel across its surface, the emitting region of 3C 273 cannot be more than a few parsecs in diameter. Variations observed to occur in a period of days and weeks imply an even smaller size. How can anything that small generate so much energy, and how can it vary that energy as rapidly as it does?

These questions are unresolved, though most astronomers believe some quasars are the incredibly energetic nuclei of young, distant galaxies. Black holes are thought to be the powerhouses behind the stupendous energies observed in quasars, though other theories for energy sources, such as giant pulsars and super-supernovae, have been proposed.

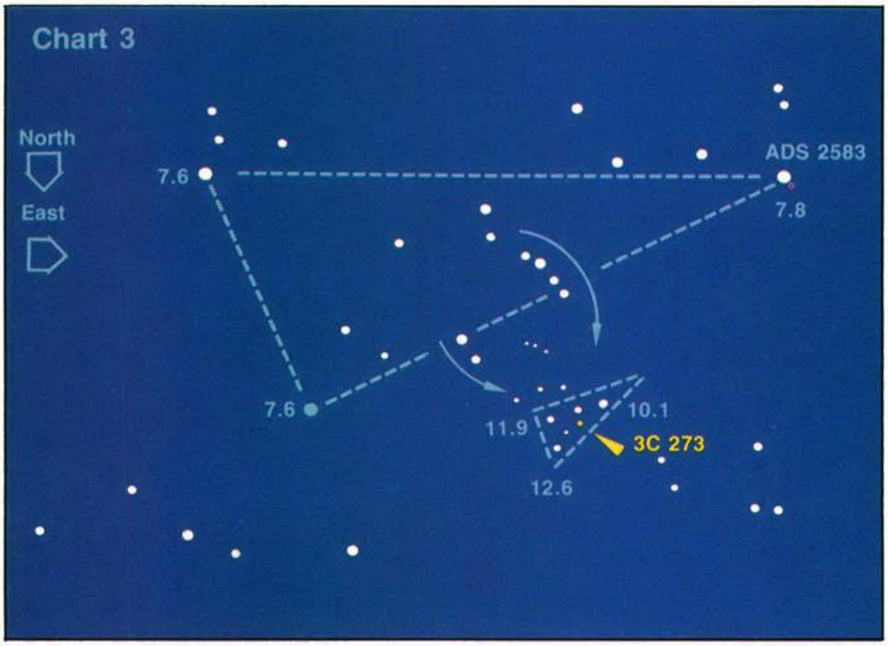
Several years ago I got the yen to see 3C 273's 3-billion-year-old photons of light. The problem was finding and identifying the quasar. At magnitude 12.8 it tends to get lost among the other faint stars in the field of view.

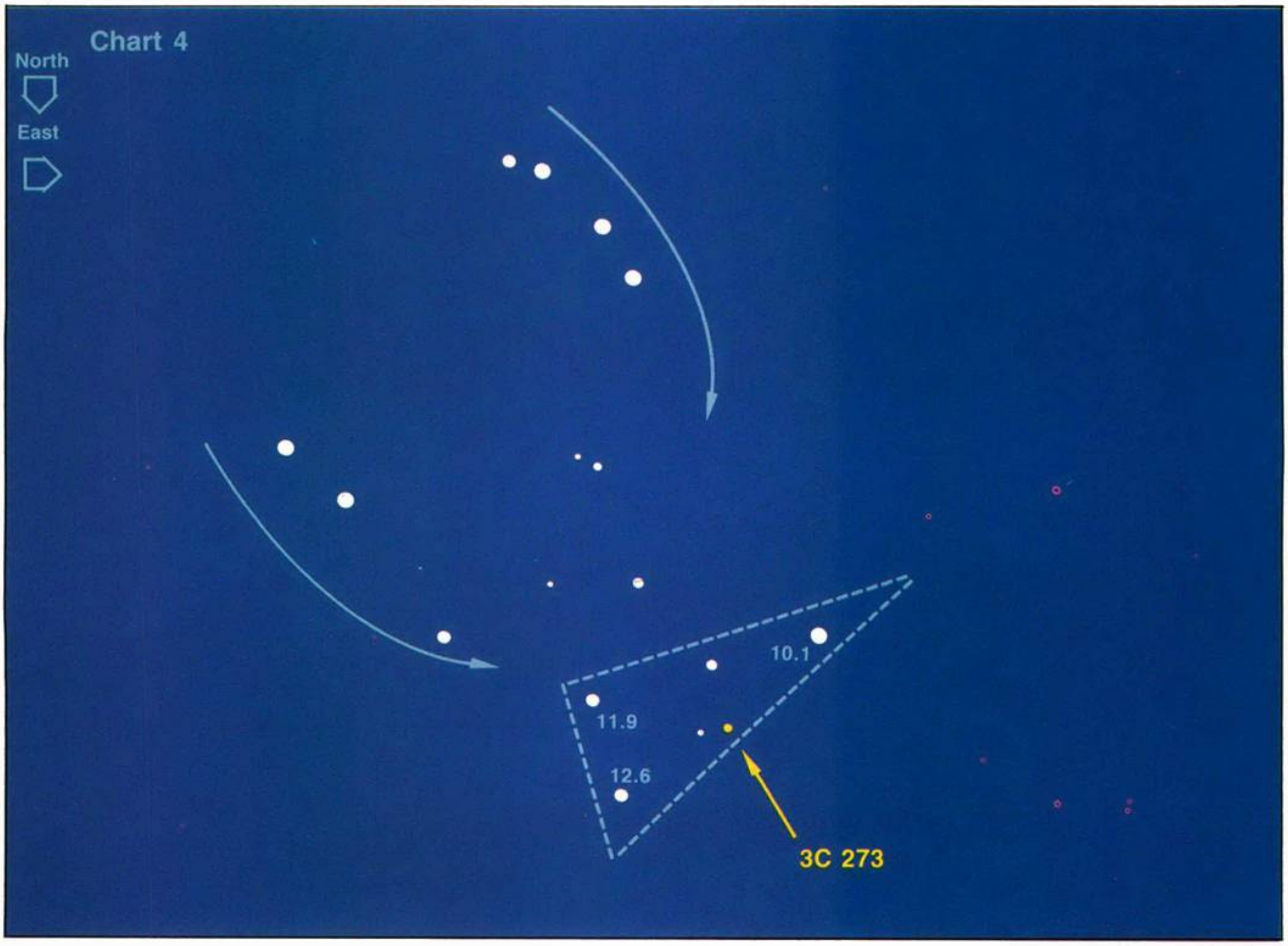
I use the star-hopping method, even though I have frequently apologized for doing so because it sounds amateurish. Then I read Leslie Peltier's statement that he never in his life used setting circles, and he was one of the greatest American amateur astronomers of this century. So I figured if it was good enough for him, I need not worry.

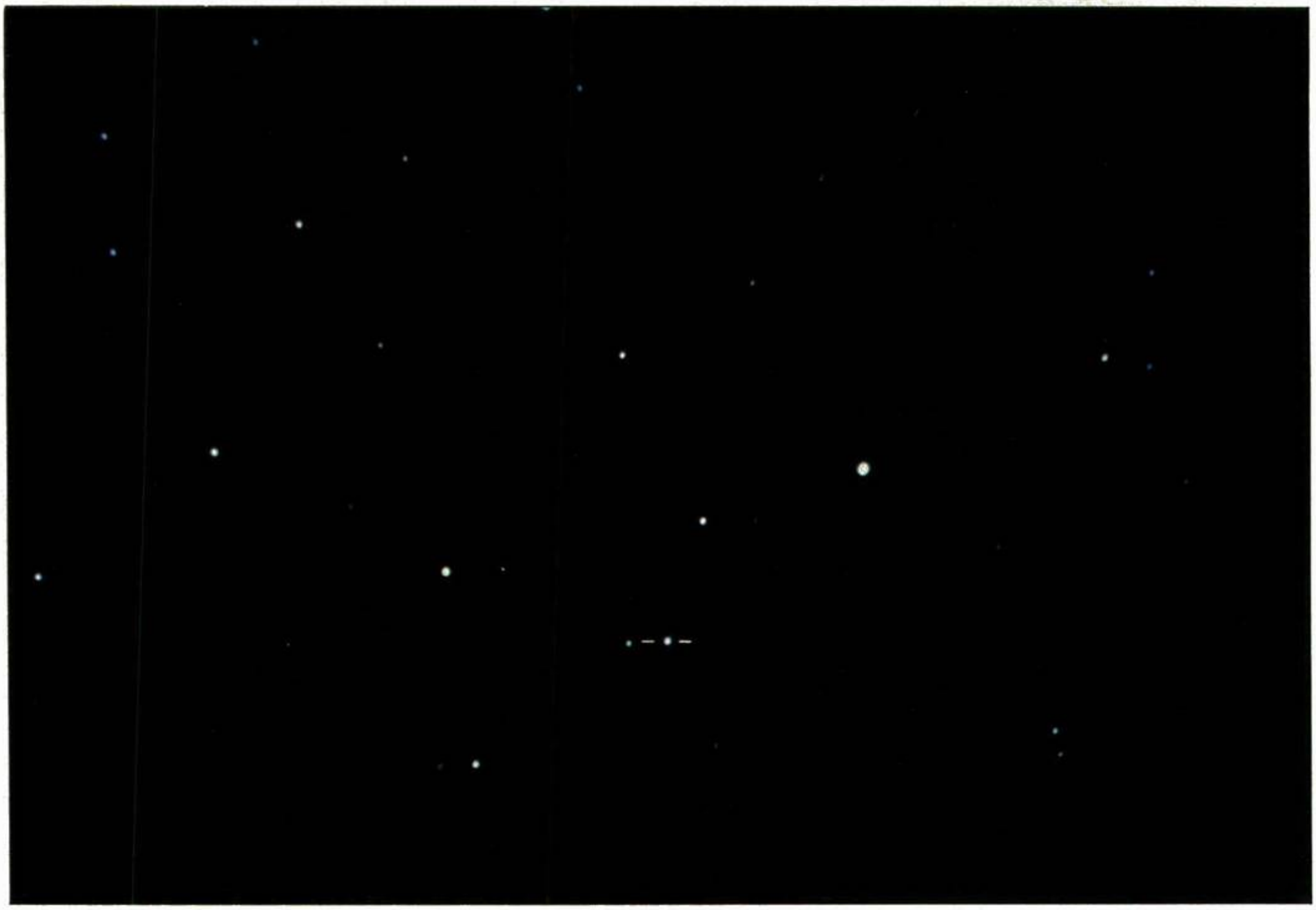
I secured a couple of fairly detailed star charts showing the 3C 273 area and started my search — with no success. I knew I was in the right part of the sky, but I couldn't find anything that corresponded to my maps. I tried some more detailed maps but still couldn't pinpoint the quasar. Eventually, using five star charts, three astrophotographs, and a whole lot of luck, I found 3C 273. But finding it shouldn't have been so difficult.

Of course, to verify a method for finding something as faint as a quasar you have to go back and find the quasar again, which I have done several times over the past several years. In fact, it has become an easy object for me to find. But in the process of becoming familiar with locating this object I discovered why the charts had not been much help.

When I star hop, I spot and remember







Although 3C 273 may look like nothing more than a bluish dot, to appear as bright as it does in our sky at its distance of 920 megaparsecs, it must be four hundred times brighter than our galaxy. Compare this photo with Chart 4 on page 51. Photo by Jack Newton.

distinctive small patterns of stars to follow, which keeps me from getting lost among the myriad stars. Fortunately, as I eventually discovered, one path to 3C 273 contains several such noticeable patterns that make the job quite easy. The problem with most star charts is that this path and the star patterns are not obvious, even if the star chart itself is accurate. The charts either don't show as many stars as can be seen in the field of view, or there is some inherent distortion caused by trying to mentally overlay the star patterns from a flat chart onto a curved sky.

And if there is an inaccuracy in the star chart, your work is really cut out for you. For example, I discovered that one of the most professional star charts I obtained had several errors, including a quite serious one: a key star making up one of the asterisms I had located in the 3C 273 field was missing!

To find and identify 3C 273 by star hopping, begin by looking at the four stars charts on pages 50 and 51. (If you use setting circles, only the fourth chart is required.) Charts 1 and 2 are oriented so north is up, and the constellations appear as they would to the unaided eye. Charts 3 and 4 are oriented with south up to correspond to the view in telescope.

Chart 1 will get you in the right area of sky — Virgo is overhead about midnight in early April. Next, go to Chart 2 to close in on the region. Find Gamma (γ) and Eta (η) Virginis, both prominent stars in a sparse region east of Leo. Verifying η Vir is simple because cuddled right next to it is a dim naked-eye companion. Due north of η Vir is a 5th-magnitude star designated as "16-c" in *Sky Atlas 2000.0*. Because of the available star patterns in the area, I find getting to 3C 273 from this star much easier than approaching it from any other direction.

Chart 2 has an arrow pointing from η Vir to 16-c Vir and a smaller arrow pointing to a right triangle consisting of two 7.6- and one 7.8-magnitude stars. This triangle is rather obvious in binoculars or viewfinders. To verify your position, note that the easternmost star in the triangle is the easy telescopic double ADS 2583 (the primary star is magnitude 7.8 and the secondary is 8.5; they are separated by 50" at position angle 290°). Move your scope so that the finder field is centered halfway between the star at the right angle and the double.

Chart 3 shows what you should see through a low- to medium-power ocular. Our right triangle is now out of view, but in its place are two new signposts. One consists of four slightly curved stars, the other of two stars curving the other way. Both point to an even dimmer right triangle, the brightest stars of which are about 10th magnitude. That little triangle is the net holding our elusive quasar.

Chart 4 zooms in on this triangle. If your eyes are well-adapted to the dark, you should see a close pair of stars just inside the longest portion of the triangle. The brighter of those points of light is 3C 273. Bingo, you've got it!

I advise going back and following the trail again, perhaps even a third time. This allows you to familiarize yourself with the three finder patterns: the large right triangle, the two curved pointer lines of stars, and the small right triangle. Tracing the path again the next night you are out viewing reinforces the path to the quasar.

As you observe this seemingly insignificant point of light, contemplate what you're looking at: an incredibly energetic object receding at 48,000 kilometers every second, over 920 megaparsecs away, and probably not more than a few parsecs in diameter. It is brighter than a hundred galaxies yet remains inscrutable to astronomers. And you can star hop to it tonight!

John Mood is a freelance science writer actively involved in amateur astronomy. His most recent article, co-written by his wife Stephanie, was "Palomar and the Politics of Light Pollution" in the November 1985 issue.

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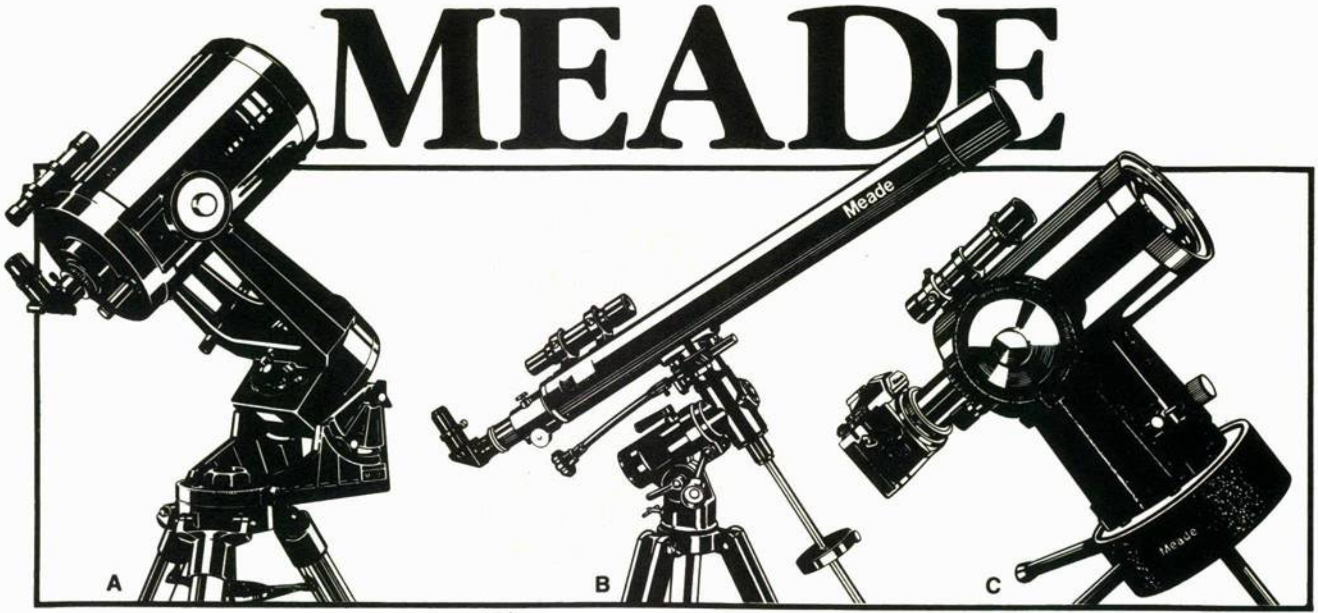

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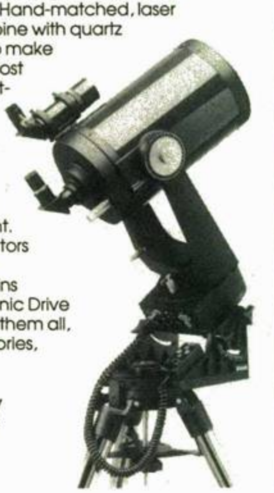

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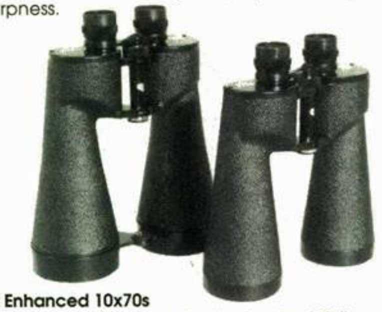

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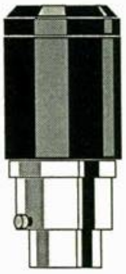

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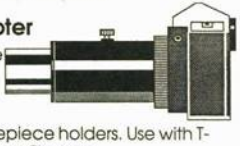

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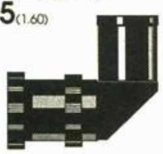

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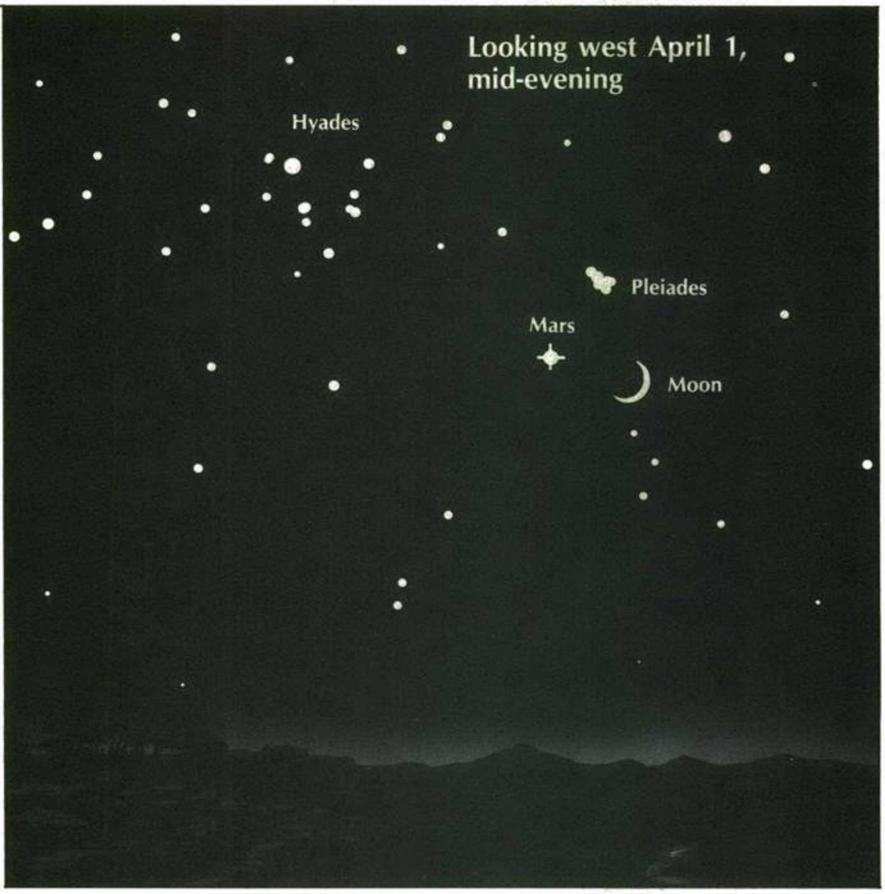
Eye on the Sky

A Lunar Occultation of Venus

by Robert Burnham



The Wanderers

In the evening sky the still-bare tree branches frame an amber-colored "star" in the west. This is the planet **Mars**, currently moving eastward against the setting stars of Taurus. Mars has a magnitude of 1.5, which is similar to that of ruddy Aldebaran in the V-shaped asterism of Taurus. On the first few evenings of April, Mars and the crescent Moon gather near the Pleiades. The grouping will be an enjoyable sight in binoculars and an opportunity for striking photographs. (Use a tripod-steadied telephoto lens, fast film, and make exposures of 0.5, 1, 2, and 5 seconds at the widest possible lens opening — this should net you at least one good shot.)

During April, watch how fast Mars moves relative to the stars. On the 1st, bright Aldebaran lies well above and to the left of Mars. On the 15th, both Mars and Aldebaran are lower and about equal in elevation. By the 30th, they have settled still lower, and Mars is now the higher of the two. While the constellations are setting, Mars' easterly motion keeps it from sliding into the twilight as fast as the stars do.

At Full Moon on April 13, the evening sky will be the scene of a **penumbral lunar eclipse**. Penumbral eclipses are usually not very dramatic, because the Moon does not enter the totally dark part of the Earth's shadow, the umbra. As a result, the dimming can range from modest to imperceptible. The eclipse begins at 7:19 p.m. CDT and ends at 11:18 p.m., but you probably won't see any darkening until around mid-eclipse (9:19 p.m.). The darkening will be strongest along the Moon's northern edge. Some observers find viewing through a neutral density photo filter helps visibility by reducing the overall glare.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

The Moon is also the principal figure in April's most spectacular event — the **occultation of Venus** on the 25th. Venus will be at magnitude −3.4 when the waning crescent Moon covers it in the predawn sky. Viewers northeast of a line from the Great Lakes region to the North Carolina seaboard must watch Venus disappear after sunrise. This is not as difficult as it sounds if you use some optical aid such as binoculars or a small telescope and darken the blue sky with a red photo filter. Southwest of the line the disappearance occurs late in twilight before sunrise. Viewers in the south central states and western plains can also see Venus reappear from behind the Moon's dark limb before the Sun rises. For viewers in the Rockies and westward, however, the whole event is over by the time the Moon and Venus rise.

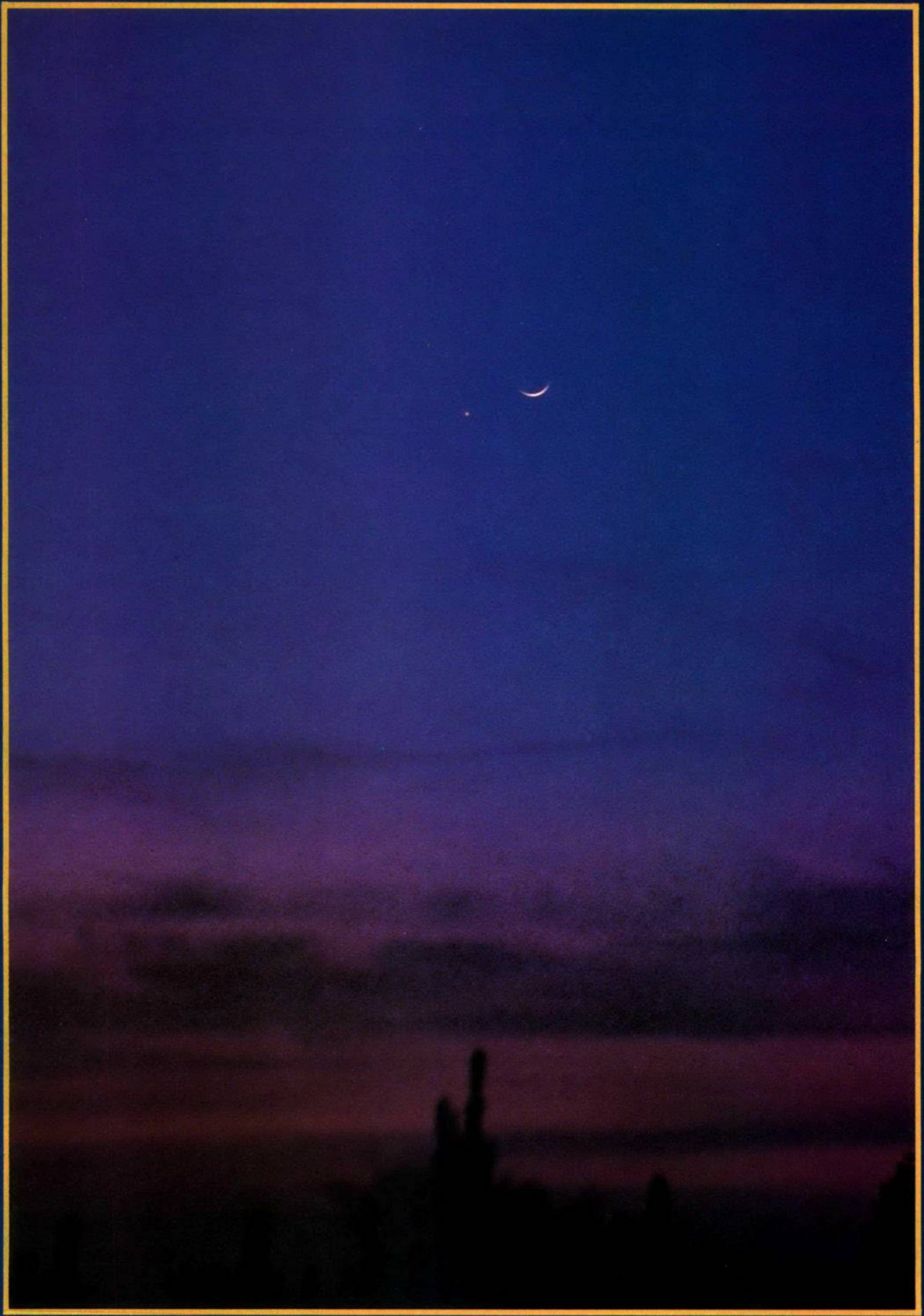
While Venus lies low in the southeast just before sunrise, **Saturn** is an impressive sight in the southern sky. Located among the stars of Ophiuchus and Scorpius, Saturn is the ivory-white object at magnitude 0.3 to the upper left of Antares. **Jupiter** lies in the morning sky also, but it won't become visible until the last few days of April. On the 30th, it lies to the lower left of Venus at half its elevation. Jupiter's magnitude is −2.1 and it shines white.

Opposite page: The Moon and Venus as they appeared during conjunction on April 10, 1986, twenty minutes after sunset. On the 25th of this month the Moon occults Venus for much of the eastern half of the United States. Photo by Gene Brings, who used a 50mm f/1.7 lens, ISO 100 film, and a 1.4-second exposure.

On April 22, the annual **Lyrid meteor shower** reaches peak activity. In a good year from a dark-sky site you can see about fifteen to twenty Lyrids each hour in the last hours before morning twilight begins. The meteors appear to radiate from a point 6° southwest of Vega. This year, however, the waning crescent Moon will reduce the numbers by about 25 percent.

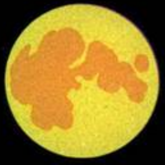
The Starry Sky

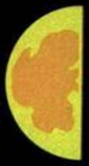
After the stellar glories of the past few months, tonight's evening sky looks empty. Many bright stars are setting, and across the southern sky stretches a vast dim expanse. Like its autumn counterpart, the spring sky calls for a little effort if you want to see it properly. Plan an evening trip away from the city in the first week of April when the Moon sets early or the last week when it rises late. From a dark country road not only will the departing stars of winter shine especially bright, but you'll be able to learn the fainter constellations of spring and miss none of their sights.



April Night Sky

First Quarter
April 6
3:48 a.m. EDT


Full Moon
April 13
10:31 p.m. EDT


Last Quarter
April 20
6:15 p.m. EDT

New Moon
April 27
9:34 p.m. EDT

1st Tonight Mars and the crescent Moon lie near the Pleiades star cluster in Taurus.

6th The Moon is farthest from Earth at 2:38 a.m. EDT: 251,232 miles (404,307 kilometers) and reaches First Quarter phase at 3:48 a.m. EDT.

13th The Moon passes north of the bright star Spica in Virgo. It is Full at 10:31 p.m. EDT, and a faint penumbral lunar eclipse will occur for viewers across North America (see text).

15th At about 10:00 p.m. local daylight time tonight the Milky Way will encircle the horizon. Looking straight up, you will be gazing past the local stars and the north pole of the Galaxy directly out into intergalactic space toward the nearest cluster of galaxies.

17th The Moon passes north of the bright star Antares in Scorpius.

18th The Moon passes 7° south of Saturn. The Moon is closest to Earth at 12:36 p.m. EDT: 229,064 miles (368,632 kilometers).

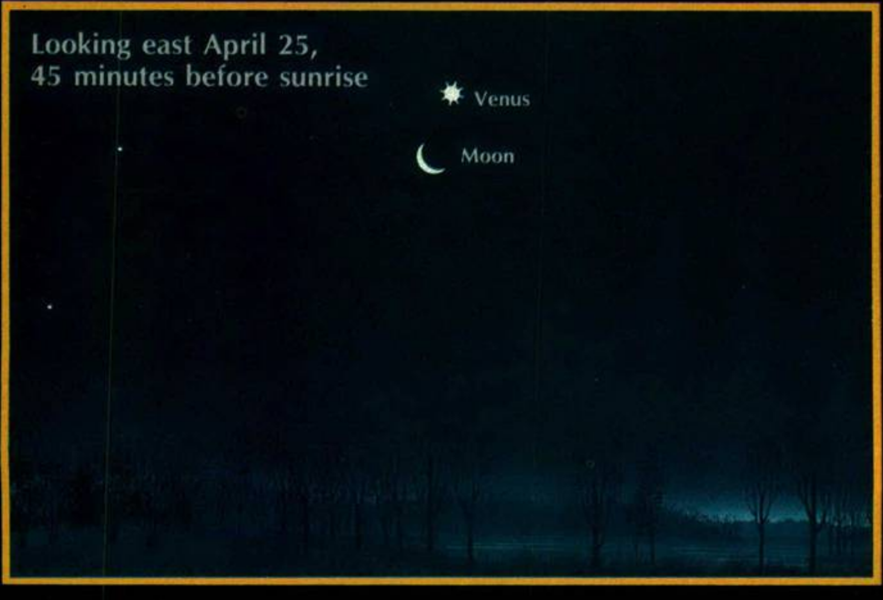
20th Last Quarter Moon occurs at 6:15 p.m. EDT.

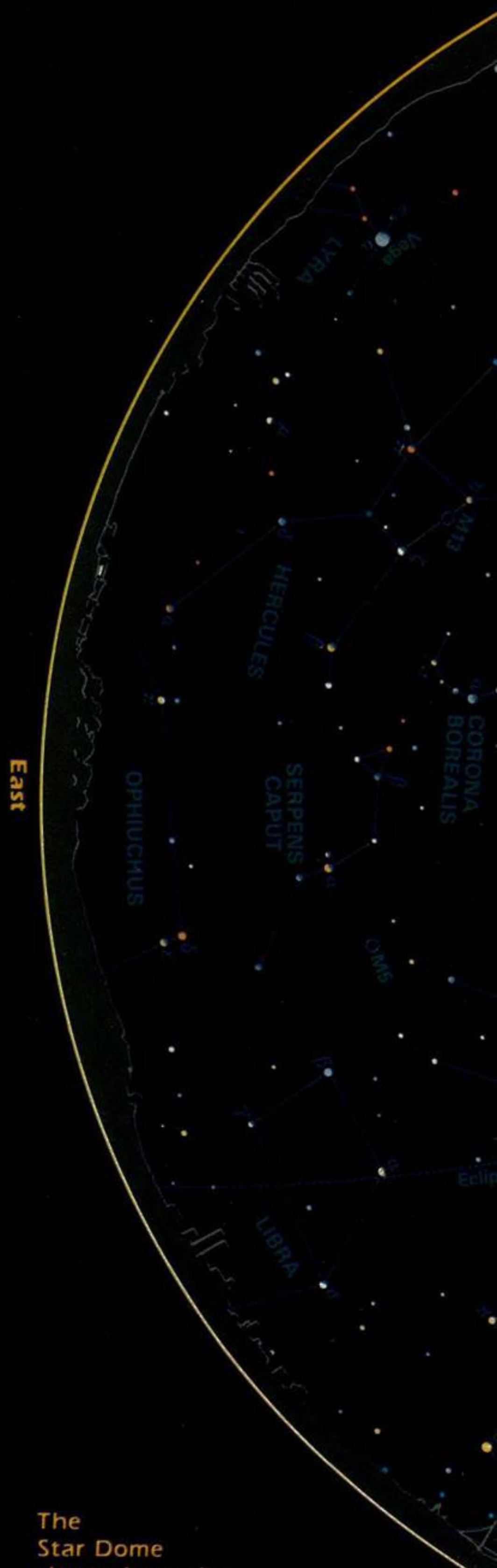
25th Venus is occulted by the Moon over much of North America (see text).

26th Jupiter is 1.4° south of the Moon.

27th New Moon is at 9:34 p.m. EDT.

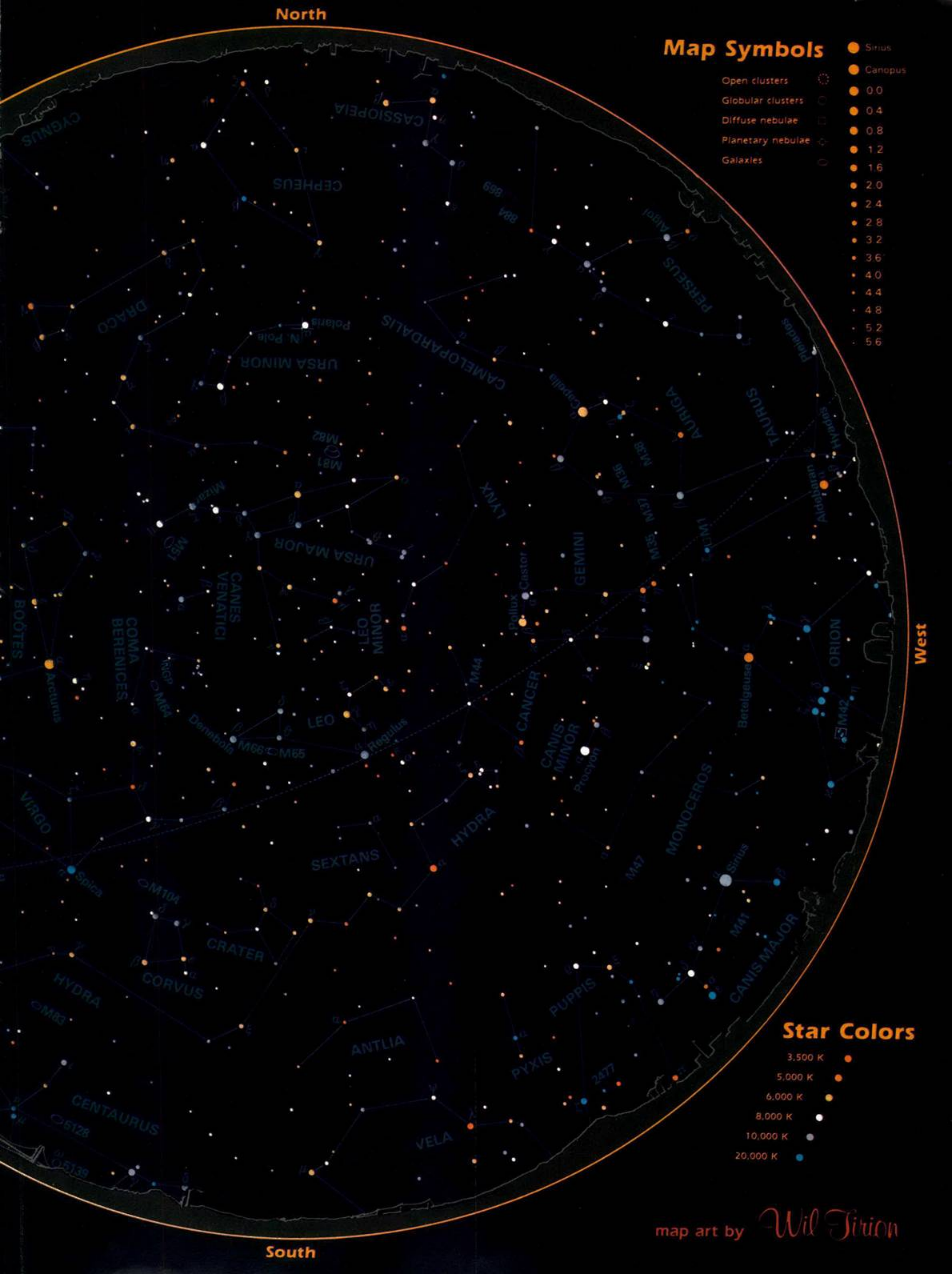
29th Pluto is at opposition.


Looking east April 25,
45 minutes before sunrise
Venus
Moon


East
LYRA
Vega
M13
HERCULES
CORONA BOREALIS
SERPENS CAPUT
OPHIUCHUS
M5
LIBRA
Eclip

The
Star Dome
shows how the
sky looks at:

9:30 p.m. standard time on April 1
9:30 p.m. daylight time on April 15
8:30 p.m. daylight time on April 30


North
South
West
Map Symbols
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
Sirius
Canopus
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
CYGNUS
CASSIOPEIA
CEPHEUS
869
884
Algol
PERSEUS
Pleiades
DRACO
Polaris
N. Pole
URSA MINOR
CAMELOPARDALIS
Capella
AURIGA
TAURUS
Hyades
M82
M81
M38
M36
M37
M35
M1
LYNX
Aldebaran
Mizar
M97
M51
URSA MAJOR
CANES VENATICI
GEMINI
Castor
Pollux
LEO MINOR
BOÖTES
COMA BERENICES
Arcturus
M100
M64
ORION
Betelgeuse
M42
M44
CANCER
LEO
Regulus
Denebola
M66
M65
CANIS MINOR
Procyon
MONOCEROS
VIRGO
HYDRA
SEXTANS
Spica
M104
M47
Sirius
M41
CANIS MAJOR
CRATER
CORVUS
HYDRA
M83
PUPPIS
ANTLIA
PYXIS
2477
CENTAURUS
5128
5139
VELA
Star Colors
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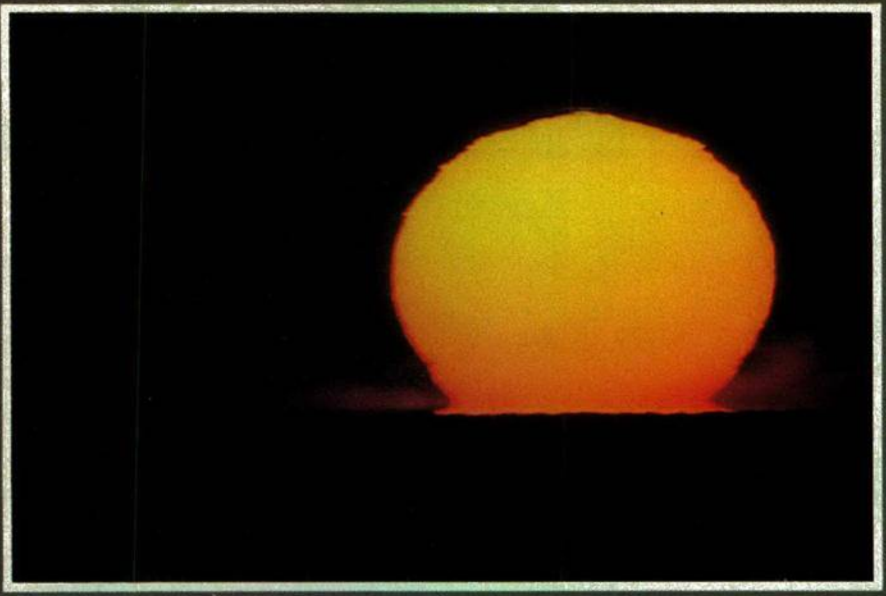
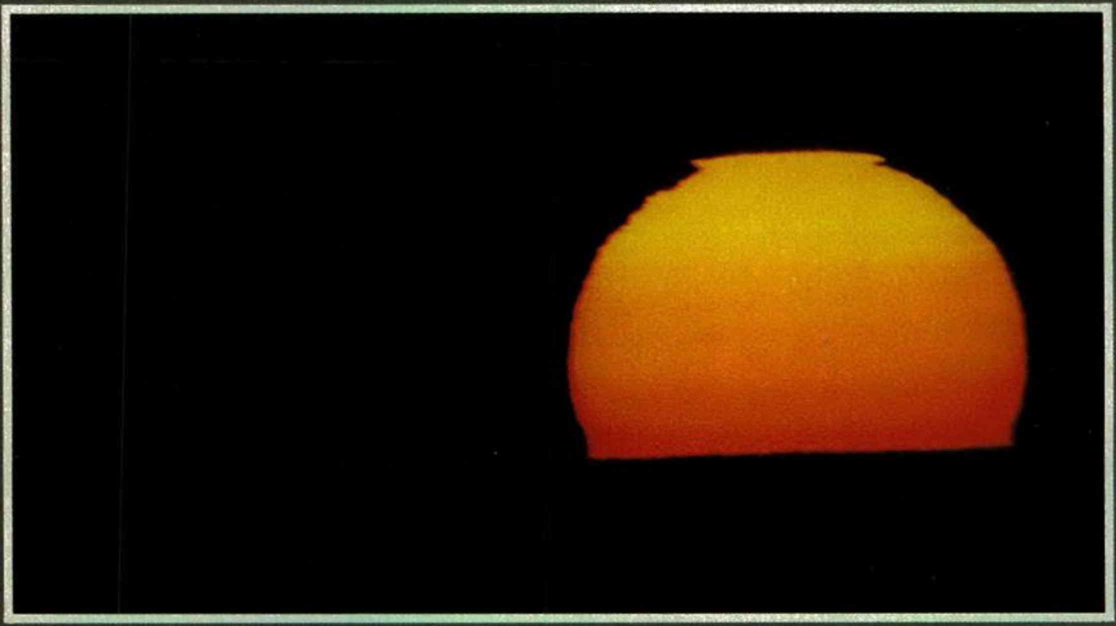
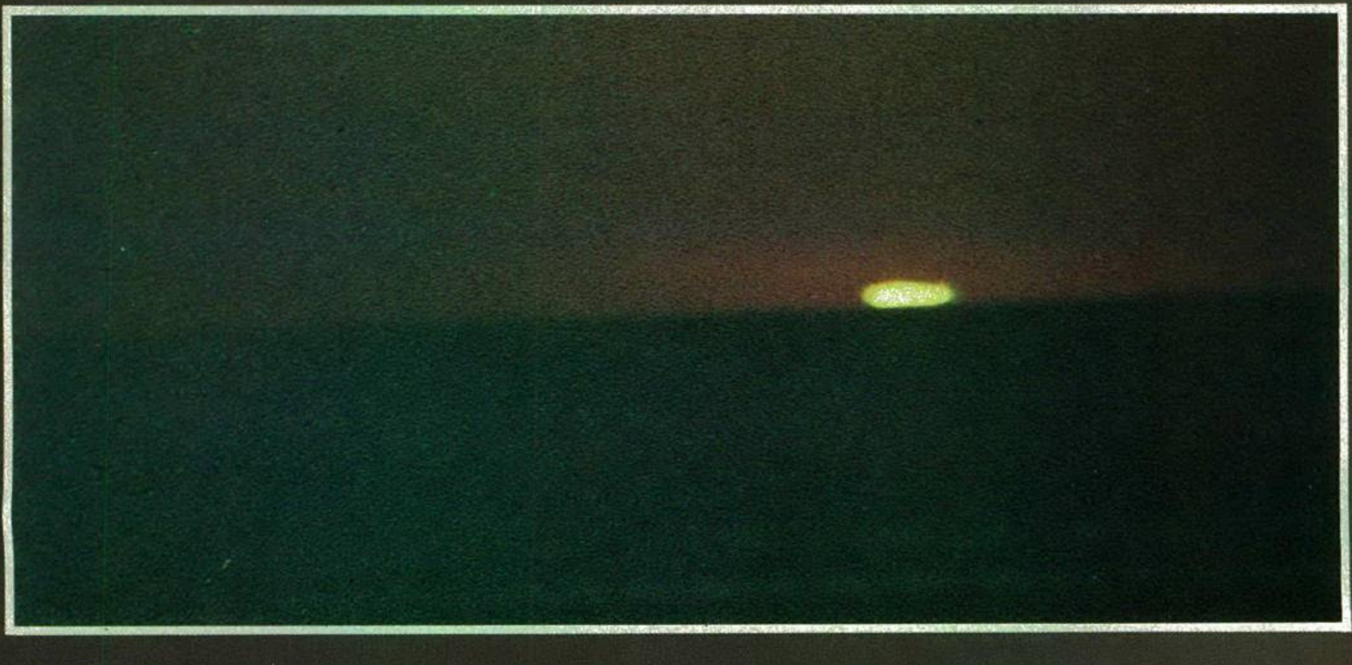
8,000 K
10,000 K
20,000 K

map art by Wil Tirion



The "green flash" is the fleeting appearance of a bright greenish light tangent to the top limb of the Sun at either sunrise or sunset. Usually the scattering of the blue-green wavelengths of sunlight by haze weakens or prevents the appearance of the green flash. However, on exceptionally clear days the refraction of blue-green light manifests itself in a flickering green light, as seen in this series of photographs by Robert C. Ausland. These photos were taken at sunset overlooking Lake Superior. Ausland writes: "[The flickers of green light] looked a lot more conspicuous than they photographed." The flash seen here lasted about one second, says Ausland, and was a "vivid emerald green." In the first photo a faint green "flame" can be seen on the top limb. Ausland used a 500mm mirror-type telephoto and a 3x tele-extender for a total focal length of 1500mm with ISO 400 film.





In the west **Orion** the Hunter is slipping behind the trees, preceded by **Taurus** the Bull. Close on Orion's heels is his faithful hound, **Canis Major**. (Notice how colorfully Sirius flashes as it sinks into the turbulent air.) Above these constellations stand the **Gemini** Twins — Castor and Pollux. To the right of Gemini we find the pentagon of **Auriga** the Charioteer and the stars of **Perseus** slipping low in the northwest. Left of Gemini shines bright Procyon, the main star in the Lesser Dog **Canis Minor**; it appears prominent because of its dim surroundings. Above Procyon scuttles **Cancer** the Crab — home to Praesepe, a loose, open star cluster hazily visible to the naked eye on very dark, transparent nights and a delight in binoculars. (The map shows it as M-44.)

High in the south, wide **Leo** the Lion crouches as if to spring on the Crab. First-magnitude Regulus is easy to locate; from it trace the backward "?" (called the Sickle) that marks Leo's head and shoulders. The Lion's hindquarters consist of a triangle with the star Denebola at the tail.

This time of year is best for learning the sky's longest constellation, **Hydra** the Water Snake (see Skylore). Hydra's brightest star is 2nd-magnitude Alphard, which means "the solitary one [of the Snake]." Hydra's head, a small elongated polygon of six 3rd-magnitude stars, lies about halfway between Regulus and Procyon. From there the Water Snake wiggles east, passing **Sextans** the Sextant, **Crater** the Cup, and **Corvus** the Crow before it ends in the southeast under **Libra** the Scales. Hydra takes six hours to cross the meridian! Below Hydra you may catch glimpses of parts of Jason's ship *Argo* — **Puppis** the Poop Deck and **Vela** the Sails — as the ship sails below the southern horizon.

Virgo the Virgin lies to the left of Leo. Its bright white star, Spica, appears more prominent in the sky than the map indicates. Above Virgo's western end is dim **Coma Berenices**, Berenice's Hair, in which the naked eye can see a very large loose star cluster like a soft cloud of light. (This is also a fine sight in binoculars.) North from Leo we pass **Leo Minor** and the Hunting Dogs, **Canes Venatici**, created by Johannes Hevelius in the late 1600s.

High over Polaris the North Star we see the Large Bear **Ursa Major**. The Bear's nose is aimed at Capella in Auriga, while her feet almost touch Leo Minor. Alpha (α) and Beta (β) are the famous pair of stars that point toward Polaris in **Ursa Minor**. The Bear's tail (also known as the handle of the Big Dipper) curves southeastward toward ruddy Arcturus in **Bootes** the Herdsman, while continuing along this arc brings you back to Spica in Virgo.

Skylore

Killing the Lernean Hydra was the second of twelve labors imposed on Hercules by King Eurystheus of Argos. In return for these labors, Hercules was to receive immortality. The large swamp of Lerna, the source of the seven-streamed river Amymone, was a few miles southwest of Argos near the Peloponnesian coast. It was a holy place of Dionysian revels and shrines to Demeter and Aphrodite, among others. But inhabiting the swamp was a fearsome beast called the Hydra. It was so evil that its mere breath could kill, as would even a whiff of its footprints.

The Hydra wasn't the only frightful creature in the family: its siblings included the Chimaera, the Sphynx, and the Nemean Lion, usually associated with Leo. (Killing the Nemean Lion, by the way, was Hercules' first labor.) Though the constellation has the form of a long snake, the mythical Hydra had the body of an immense dog surmounted by many heads — nine, according to Apollodorus, but others say 50, 100, or even 10,000.

Hercules rode into the swamp accompanied by his nephew Iolaus. Hercules shot fire-arrows into the Hydra's lair to lure the beast out. Iolaus then set the nearby shrubs on fire to confuse the creature while Herclues clubbed and hacked at its many heads, holding his breath to avoid the fatal stench. But when he chopped one head off, two grew in its place. Just as Hercules made this frightening discovery, Hera sent a crab (represented by Cancer) to distract him by nipping his feet. She hated Hercules because he was the result of her husband Zeus' dalliance with a mortal woman. Impatiently, Hercules stamped the crab into the ground.

Soon the hero found that if a Hydra neck stump was burned, no new heads grew; Iolaus was then commanded to cauterize the stumps with a flaming branch. At long last the middle and immortal head fell to Hercules' sword and, spitting with fury, it was crushed under a large rock. The Hydra was no more.

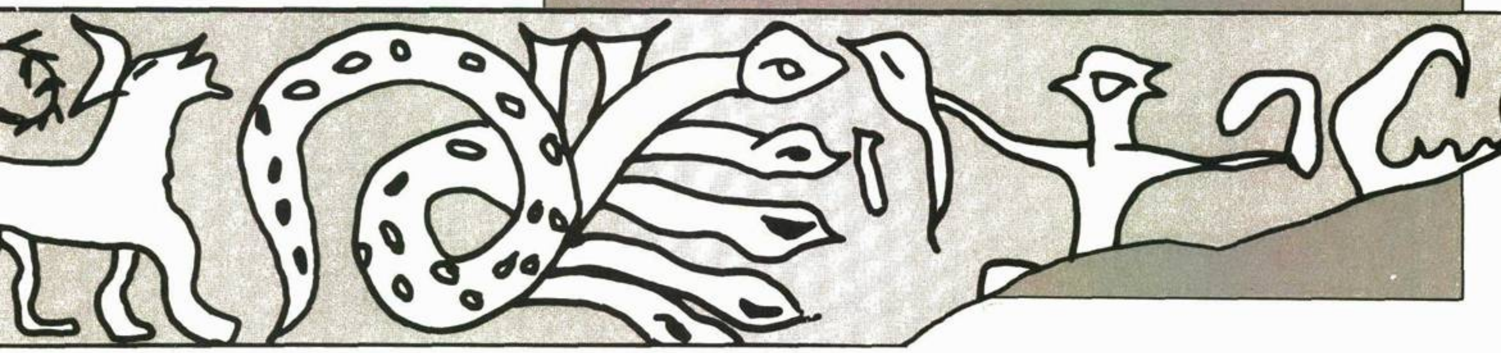
Colorful as the story is, the monster was already ancient by Homer's time. In Sumerian mythology, from which the Greeks borrowed much, the constellation was connected with the goddess Tiamat, primeval ruler of sea-water and chaos and mother of all the lesser gods. Tiamat was plotting to destroy her many offspring for their complicity in the murder of her husband Apsu, ruler of the fresh waters. When they heard of her plans, the gods summoned a great hero, Marduk, and sent him forth to battle Tiamat and her hosts. Surviving clay tablets describe a long battle in tedious detail, but in the end Marduk triumphed. And from the sundered parts of Tiamat's body Marduk created heaven and earth, and so the world began.

In the Sumerian story Tiamat has no specified form. But a cylinder seal that dates from before 2500 B.C. shows a kneeling man, presumably Marduk, battling with a seven-headed snakelike monster. Nearby writhes an ordinary snake, while many pairs of scorpions clash pincer to pincer. Although it is hard to be sure just what the seal depicts, the juxtaposition of several well-known zodiacal figures certainly suggests an astronomical subject.

This obviously isn't our Hydra legend pure and plain. But the parallels are close enough that we can easily imagine the essence of the story traveling down through the millennia and being translated into Greek where, embellished with local color, it became the Lernean Hydra and Hercules.

Did killing the Hydra help Hercules achieve immortality? Well, no. It seems King Erystheus had a legalistic turn of mind and refused to accept this labor because Hercules was helped by Iolaus!

This sketch of a cylinder seal, dated 2500 B.C., shows a kneeling man battling with a seven-headed snake.



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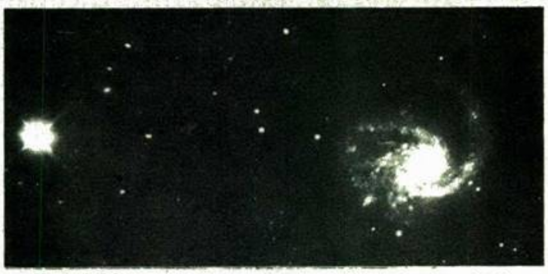
LUMICON Carries a full line of telescopes & accessories. Fast Delivery, competitive prices. Both Catalogues $3.

LUMICON FOR HIGH PERFORMANCE

ASTROPHOTO OF THE MONTH



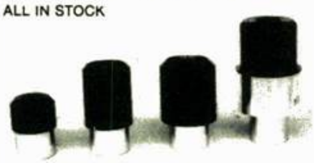
Spiral Galaxy M-99 (NGC 4254) in Coma Berenices. Spiral structure detail can be seen visually for this 10th magnitude galaxy. 40 minute photo by Dr. Jack Marling using hypered 2415 film, 24" f/6 telescope and LUMICON Giant EASY-GUIDER.

20mm NAGLER

Also new 12mm & 16mm NAGLERS

TELE VUE™ EYEPIECES USE THE BEST!!

ALL IN STOCK



Renaissance 4" f/5.5. Telescope	$1395
7.4, 10.4, 13, 17, 21, 26mm Plossl, 50°	**$89**
1.8X or 2.5X Tele Vue Barlow Lens	**$89**
32mm Plossl, widest true field in 1¼"	**$109**
55mm 2" Plossl, widest possible field	**$190**
15mm Wide-Field, 1¼" eyepiece, 65°	**$129**
19mm Wide-Field, 1¼" eyepiece, 85°	**$139**
24mm Wide-Field, "superb," 65°	**$159**
32mm Wide-Field, 2" eyepiece, 65°	**$229**
40mm Wide-Field, "awesome," 65°	**$289**
4.8mm Nagler, 82° field	**$149**
7mm Nagler, 1¼" eyepiece, 82° field	**$185**
9mm Nagler, 82° field, "the best"	**$219**
11mm Nagler, 82° field, 1¼" or 2"	**$235**
13mm Nagler, 82° field, 1¼" or 2"	**$249**
12mm Nagler, type II, 82°, 1¼"/2"	**$249**
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Central Star Filter (blue tri-color) 340-470nm bandpass	**$35**
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48mm Polarizer (2 make variable density)	**$18**
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H-ALPHA PASS FILTER

Yields spectacular contrast gains in B&W photography with telephoto lenses. Yields pinpoint star images. Superb with hypered 2415. For color, use the Minus Violet (MV) Filter.

Specify Lens Size	**H-Alpha**	**(MV)**
46, 48, 49mm	$35.00	$29.00
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67, 72, 77mm	$52.00	$45.00
82mm	$55.00	

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The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave

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90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.

1¼" (1.32" mirror)	**$89.50**
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UHC Filter™

ULTRA HIGH CONTRAST

The **LUMICON UHC FILTER** is specially designed for visual astronomy in areas of severe light pollution or for viewing very faint nebulae at any location. **UHC** stands for **U**ltra **H**igh **C**ontrast and this filter is guaranteed to yield a higher visual contrast on planetary and emission nebulae than any other filter at any price. 24nm visible bandpass, 482-506nm. Transmission = 85-95%.

"I CAN SEE THE OWL NEBULA!"

Tom Kramer saw the Owl Nebula, M-97, for the first time using a LUMICON UHC Filter. He stated, *"I had never seen M-97. . . I attached the UHC Filter and tried again. M-97 was right there. I could not believe it! The UHC Filter should be standard equipment."* **Tom Kramer, Sayville, NY**

For optimum astronomy, use either the **LUMICON DEEP-SKY Filter** or the **LUMICON UHC Filter**

DEEP-SKY FILTER™

The **LUMICON DEEP-SKY FILTER** improves your view of **all** deep-sky objects including galaxies and comets. It removes natural and man-made light pollution and yields 3-6x contrast gain for nebulae and 1-3x contrast gain for clusters and galaxies. It is ideal for **both** visual use and B&W or color photography. This gentle filter yields the most natural view of any LPR filter available today. 90nm visible bandpass. 442-532nm. H-Alpha 656nm transmission = 85-95%. Visible transmission = 90-95%.

	Standard	**Premium***
0.96" LUMICON DEEP-SKY Filter threads into most 0.96" eyepieces		**$59.50**
1¼" LUMICON DEEP-SKY Filter threads into most 1¼" eyepieces		**$79.50**
48mm LUMICON DEEP-SKY Filter (1.75" aperture), threads into most 2" eyepieces. Also fits LUMICON EASY-GUIDERS		**$119.50**
2" LUMICON DEEP-SKY Filter (1.5" aperture), threads into most 2" eyepieces. Also has male & female camera T-threads for prime focus photography	**$99.50**	**$119.50**
72mm LUMICON Giant DEEP-SKY Filter (62, 67, 77mm adapter, $8)		**$299.50**
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48mm LUMICON UHC Filter (1.75" aperture) fits most 2" eyepieces	**$159.50**	**$199.50**
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Telephoto lens adapter for 2" or 48mm filter. Select 46, 49, 52, 55, 58mm		**$6.95**
Universal adapter for 1¼" filters. Adapts the 1¼" filters to any 1¼" eyepiece		**$16.00**
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**Premium filters are selected best of the lot and typically have 5-10% higher transmission. Not always available. Include individually measured transmission data.*

DEEP-SKY ASTROPHOTOGRAPHY

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U.S. Patent 4,473,636

MAKE YOUR OWN HYPERED FILM

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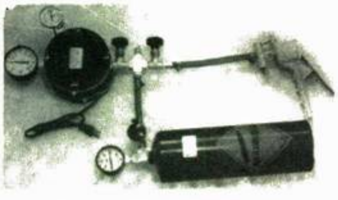

MODEL 600 HYPER-KIT [See Photo] Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates **$350.00**

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All **LUMICON EASY-GUIDER**™ off-axis guiders† have both radial and 360° rotational adjustments for 5X eaiser guide-star selection, use 48mm filters, 360° camera rotation, large prisms fo bright guide-starts. *Specify Camera and Telescope type.*
U.S. Patent # 4,448,500

NEWTONIAN EASY-GUIDER™

Full aperature. Installs in secs. Specify 2" or 1¼".

NEWTONIAN EASY-GUIDER	**$169.50**
3X Relay Diagonal (see photo)	**$79.50**
Illuminated reticle eyepiece system	**$89.50**

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CASSEGRAIN EASY-GUIDER™

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CASSEGRAIN EASY-GUIDER **$225.00**
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For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

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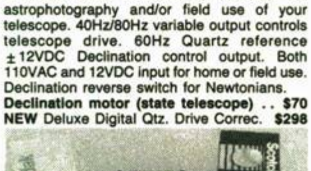
NEW Deluxe Digital Qtz. Drive Correc. **$298**



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Film Type, 35mm	**Exposures**	**Price**
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SR1600, fastest of all, color neg	24	**$12.95**
Konica SR200, fine grain color neg	12	**$9.95**
3M 1000, fastest slide film	20	**$12.95**
Fujichrome RD100, fine grain slide	24	**$12.95**
5072, color slides from neg	36	**$6.95**
D-19 B&W Developer	1 gal.	**$6.95**

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MEADE 2080/LX3 w/MCSO $1685

#712 Dew shield (8") and accessory tray ($140 list) **add $89**

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Accessory shelf for field tripod ($40 list) **$32**
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#38 declination motor and clutch ($150 list) **$99**
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2080/LX3
$1685
2080/LX3
W/MCSO

NEW! Quartz Drive Meade 2080/LX3

The Meade 2080/LX3 with built-in quartz electronic drive system is positively the highest performance 8" Schmidt-Cassegrain telescope system available today.

2120/LX3 10'' System w/MCSO $2590

The 10" Meade 2120/LX3 collects 56% more light than an 8" telescope for significantly improved viewing and astrophotography. It has all the features of the 2080/LX3 (see Meade ads in this magazine for full list of features.)

4'' MEADE 2045 w/table tripod $598

NEW! Meade 2045/LX3 w/quartz drive **$795**

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NEW!
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Meade Model 2045 — Advanced engineering and superb optical performance in a beautiful ultraportable system.

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See Meade 2080/LX3 options
Wedge & field tripod for Meade 2045 ($380 list) **$298**
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SUPER

MEADE
2080/GEM
$885,
w/MCSO
$998

SALE

MEADE
2120/GEM
$1799,
w/MCSO
$1949

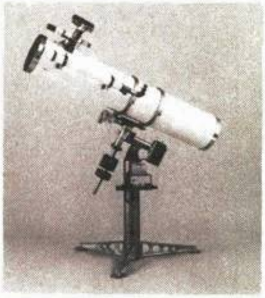
The Meade 2080/GEM and 2120/GEM telescopes include the same diffraction limited optics as the 2080/2120/LX3. Large, stable German Equatorial Mount (GEM) with setting circles, slow motion controls on both axes, large 8X50mm finderscope, 25mm 1¼" eyepiece, integrated polar alignment scope, and heavy duty adjustable height tripod (hardwood for 2080, metal for 2120). The computer control provides automatic object location from an extensive software library of deep-sky objects.

Meade 2080/GEM, 8" f/10 Schmidt-Cassegrain telescope with equatorial mount ($2100 list) **$885**
Meade 2080/GEM with Multi-coated silvered optics (MCSO) increases transmission 18% ($2300 list) **$998**
Meade 2120GEM, 10" f/10 Schmidt-Cassegrain telescope with equatorial mount ($4100 list) **$1799**
Meade 2120/GEM, 10" f/10 with equatorial mount **and with multi-coated silvered optics** ($4300 list) **$1949**
Dew shield for 2080/GEM .... **$72** Dew shield & accessory tray for 2120/GEM **$144**
#785 motor and quartz drive corrector system (for photography). **Highly Recommended** ($310 list) **$219**
#3000 computer control system provides automatic celestial object location ($1500 list) .... **add $985**
LUMICON Cassegrain EASY-GUIDER™ with adapter for superb rich-field viewing & photography **$239**
LUMICON DEEP-SKY Filter™ improves **both** viewing and photography, 1¼" premium ..... **$79.50** 48mm **$119.50**

8'' f/6 NEWTONIAN.........$995

$698
(Model 628)

$798
(Model 628C)
6'' f/8 with
motor drive



Model 826, 8'' f/6 Telescope w/accessories

Model 628, 6" f/8 with motor drive ($1220 list) **$698**
Model 628C, 628 w/2" focuser, 8x50mm finder ($1500) . **$798**
Model 826C, 8" f/6 with motor drive, #680 2" focuser and 8x50mm finderscope ($1640 list) **$995**
—Collects 78% more light than a 6" telescope.

These Meade Deluxe Series reflecting Telescopes have superb image quality at low or high power. They include an equatorial mount with motor drive, pier, legs, setting circles, 2" rack & pinion focuser, 8X50 finderscope (628C & 826C only), 25mm (48X) and 9mm (135X) 1¼" eyepieces, altitude and azimuth fine adjustments for polar alignment.

#43 drive corrector uses 12VDC ($130 list) **$99**
#47M Dual-axis drive corrector & elec. dec. **$340**
1¼" or 2" EASY-GUIDER (state camera) **$169**

OPTIONS BOOST PERFORMANCE

LUMICON UHC Filter for nebulae. Standard 1¼" **$79**
Prem 1¼", **$99;** Std 48mm, **$159.50;** Prem 48mm, **$199.50**
LUMICON Deep-Sky Filter, 1¼" Premium **$79**
48mm Prem Deep-Sky ..... **$119.50, $99.95** w/Easy-Guider
Adapter for viewing w/1¼" eyepiece **$20**
Dust covers. Keep optics clean. For 6" **$16/pair**
8" .... **$20/pair;** 10" .... **$18;** 16" **$24**
LUMICON Rich-Field Viewer (2080) **$140**
LUMICON Newtonian Easy-Guider, 1¼" or 2" **$169**
#122 2X Barlow ($70 list) **$56**
Dual-axis drive corr. and elec. dec. for 2080/LX3 ... **$198**
for model 628, 826, DS-10 .... **$340** for DS-16 .... **$440**
Tele Vue 32mm Plossl 1¼" eyepiece .... **add $99**
LUMICON Cassegrain EASY-GUIDER for Meade 2045, 2080/LX3 and 2080/GEM (state camera) **$225**
Illuminated reticle eyepiece & battery pack **$89.00**

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All telescopes shipped F.O.B. Livermore

6'' f/5 NEWTONIAN........$695

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AT 1985
PRICES!

Models 6600 (6" f/5) & **8800** (8" f/4.5) telescopes
Model 6600, 6" f/5 Newtonian telescopes ($1400 list) . . **$695**
—Best performance & value; bright, wide views.
Model 8800, 8" f/4.5 Newtonian Telescopes ($1800) . . . **$895**
—Collects 78% more light than a 6" telescope.

These Meade Professional Series reflecting telescopes yield superb rich-field viewing w/bright images. They include an equatorial mount w/adjustable tripod, setting circles, slow motion controls, 6x30mm view-finder, 1¼" focuser, 25mm & 9mm 1¼" eyepieces & accessory tray.

#784 motor & quartz drive corrector ($310 list) **$219**
Basic camera adapter (for moon & planets) **$32**
1¼" LUMICON Easy-Guider (state camera) **$169**

16'' f/4.5 NEWTONIAN......$1995

STILL
AVAILABLE
AT 1985
PRICES!

Meade DS-16A with Accessories

The DS Series of 10" and 16" reflecting telescopes are ideal for deep-sky viewing and photography.

DS-10A, 10" f/4.5 with motor drive ($1600 list) **$995**
—Gathers 56% more light than an 8" telescope
DS-16A, 16" f/4.5 with motor drive ($3140 list) **$1995**
Sealmaster ball bearings, highly recommended . . . **add $229**
—Gathers 400% more light than an 8" telescope

Both the DS-10A and DS-16A telescopes include an equatorial mount, #680 2" focuser, motor drive, setting circles and 25mm 1¼" eyepieces. The DS-10A is shipped freight collect.

6x30mm finderscope with brackets ($56 list) **$42**
8x50mm finderscope with brackets ($130 list) **$96**

Equipment Atlas

How to Build and Use an All-Sky Camera

by Jeffrey Charles, Robert Reeves, and Chris Schur

Photographing the entire sky in a single exposure — now there's a challenge! Conventional lenses can't do it. A 35mm wide-angle lens records a chunk of sky about 60° wide, so you might just manage to squeeze the whole sky into ten exposures. Even one of those ultra-wide 18mm lenses only takes in 100°, so you might get by with five or six shots for all-sky coverage.

The ultimate wide-angle lens is the 6mm f/2.8 fisheye produced by Nikon. With a 220°-field of view it'll pull in the whole sky and then some. Sounds great until you realize you would probably have to sell your house to raise the cash for the *downpayment* on one of these optical wonders.

But there's also an inexpensive way to take high-quality photos covering 140° or more: photographing the sky's reflection in a convex mirror. It's easy to do. You can use the camera you now own and, best of all, your all-sky camera can be assembled from common automotive and hardware store parts in an evening.

Subjects for such an all-sky rig include the Milky Way, a "sky full" of constellations, and the path of the Moon across the sky with time-lapse photography. You can capture the entire zodiacal light cone and band in one frame of film, show meteor showers and their radiants, and record full-sky aurorae with their wide ranges of colors. By shooting pictures every hour or so, you can record the stars wheeling across the sky during the course of a night. In the daytime you might use an all-sky camera to photograph cloud patterns, the passage of weather fronts, crepuscular rays from the Sun, and rainbows.

How does it work? You suspend a 35mm camera over a convex mirror and focus on the reflected image of the sky. Depending on the size and curvature of the mirror, you may be able to record somewhat more than 180°, though 180° is adequate to record the whole sky. (Using a L'eggs egg as the reflector, you can record 320°!) The camera and its support appear in the reflection, of course, but they do not block much of the sky.

Finding a good mirror is the key to a good all-sky camera. The mirror must have a smooth, unwrinkled surface on which a reflective coating has been applied. You can see this in the store by how cleanly the surface reflects the overhead lights. Second surface reflectors (mirrors with silver *behind* glass) are generally not acceptable. To cover a full 180°, the reflector need only be an 80° segment of a sphere, rather than the 90° you might expect. This is because the line from your camera lens to the edge of the reflector is typically inclined 10° from the optical axis. It's not easy to tell how much curvature a given mirror has, so try several before you pick one.

You can photograph everything around you with an all-sky camera. Photo by Jeffrey Charles.

Ideally your reflector should be fairly large, at least 6 inches in diameter, and preferably 9 or 10 inches. If the reflector is small, you'll have to place the camera close to it. Then, because the depth of focus of a camera lens is shallow at close distances, the camera lens would have to be stopped down. For astronomical photography this pretty much rules out small aluminized condenser lenses, L'eggs eggs, or the Spiratone "Bird's Eye Lens" attachment, though they may still be suitable for daytime all-sky cameras. Fortunately, this is a minimal problem for 6-inch diameter or larger reflectors.

After experimenting with a wide variety of curved reflective surfaces such as surveillance mirrors, Christmas tree ornaments, chromed plastic containers, and hemispherical deodorant-can tops, we found that most successful designs employed convex chrome-plated hubcaps available at most auto parts stores.

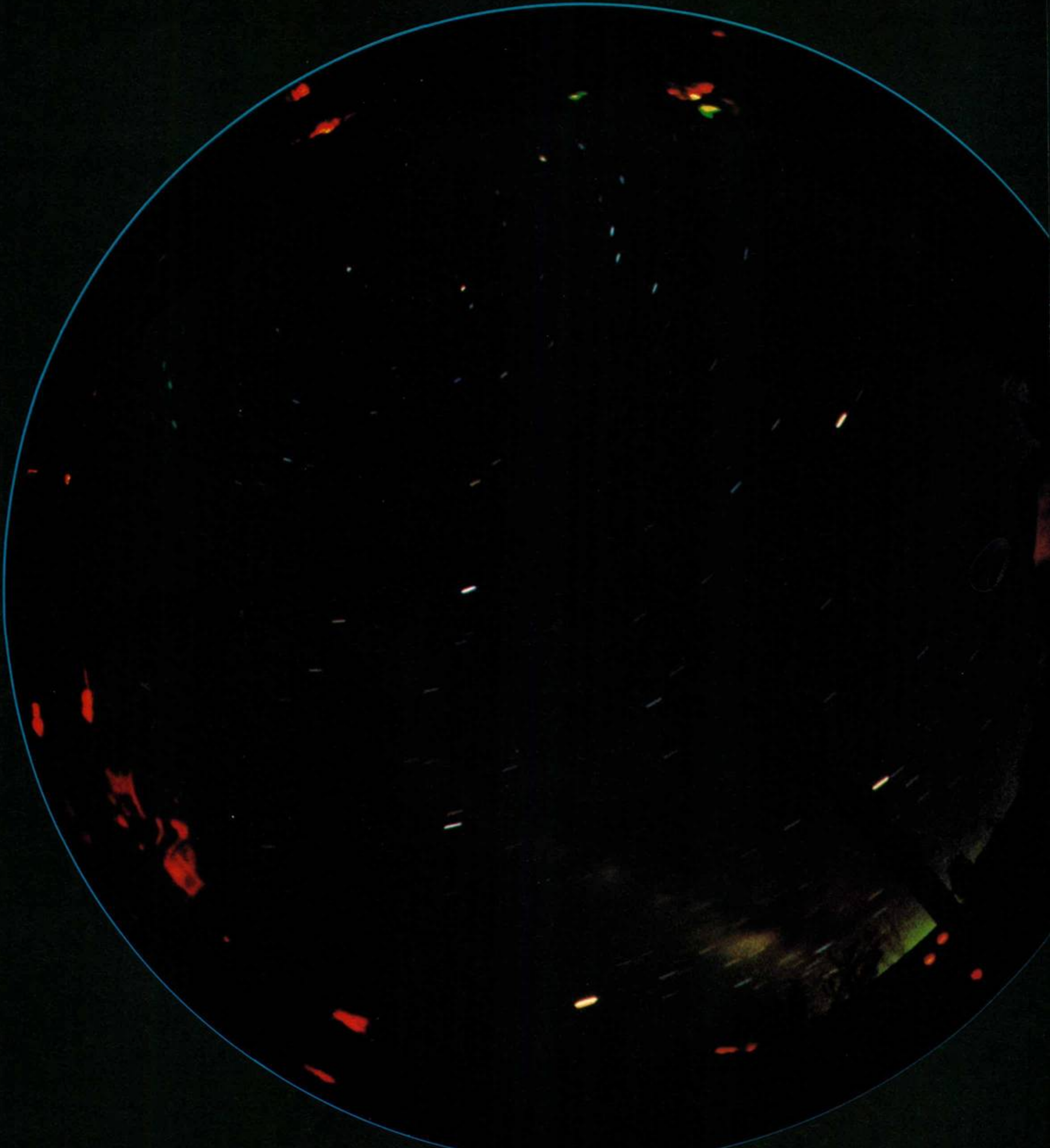
To test hubcaps or other shiny convex mirrors for suitability as all-sky reflectors, mount your camera on a photo tripod a couple feet above the mirror surface. Aim the camera downward, adjust the camera's height until the hubcap just fills the frame, and then focus the camera lens so distant objects are crisply rendered in the hubcap. You may have to try several hubcaps before you find a good one. Chris Schur tested a lot of hubcaps and discovered that the best kind are chrome-plated "Moon"-brand hubcaps. They meet all the criteria for a good all-sky mirror and are both lightweight and inexpensive.

The next best reflectors are the wide-angle spot mirrors that attach to truck rear-view mirrors. Take the glass out of an 8-inch spot mirror and mount it on the base of your platform with clips cut from soft plastic.

Building an All-Sky Camera

The simplest all-sky camera consists of a base to hold the reflector, a ring with a bracket to hold the camera, and three ⅜-inch threaded rods to join the base and the ring. The base and ring are pieces of ½-inch or ¾-inch plywood.

Cut the ⅜-inch threaded camera support rods, which usually come in 3-foot lengths, short enough so the reflector fills at least three-fourths of the height of the frame. A camera bracket made from an ordinary hardware store angle bracket and a ¼"-20 bolt with a wing nut works just fine. (The threads on the bottom of your camera are size ¼"-20.) Paint everything flat black to minimize reflections and then

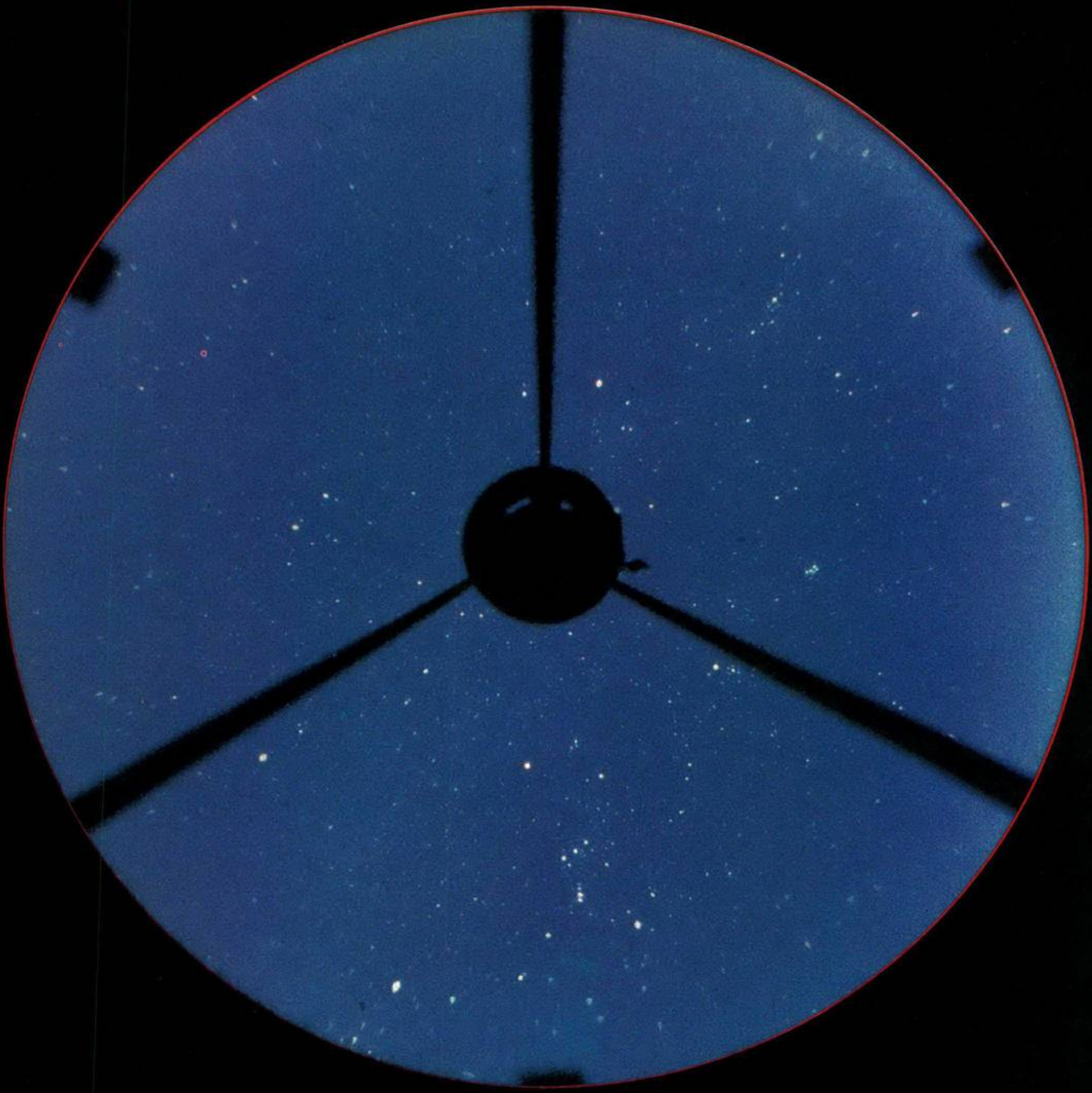


mount the mirror with a bead of bathtub caulk or with clips cut from soft plastic.

You can build a more permanent and better-looking camera support using three plywood arches instead of threaded rod. Arches cut from ½-inch-thick plywood are both strong and light and form a rigid support for the camera at the correct spacing. Place the base of the supports at least 6 inches from the edge of the hubcap to keep the reflected images of the struts as unobtrusive as possible.

If the camera support struts really annoy you, it's possible to get rid of them entirely by hiding the camera support rod within the reflection of the camera body itself. A single strut made from a threaded rod is

With the camera suspended above a hubcap, Chris Schur and Jeffrey Charles exposed Fuji RD100 film for 10 minutes to record this horizon-to-horizon view of the night sky over Sedona, Arizona. The camera has a 50mm f/2.8 lens. Note the broad band of Milky Way crossing the heavens. Saturn is the bright "star" in Scorpius.



Canis Major, Orion, Taurus, Gemini, Auriga, Perseus, and even part of Cassiopeia crowd together in a single 8-minute exposure by Robert Reeves. His all-sky camera, mounted on a Schmidt-Cassegrain telescope, was pointed straight up. The telescope's drive provided tracking. Reeves set the camera aperture to f/2.8 and used Agfa 1000 slide film. The photo on page 70 shows his all-sky rig.

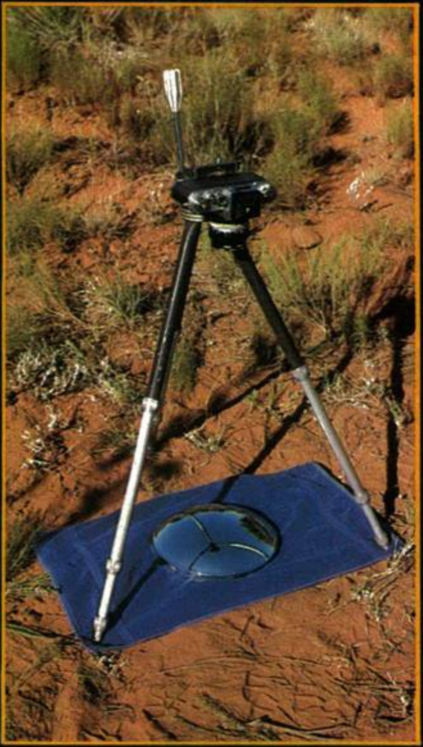
placed between the center of the hubcap and the center of a ¾-inch-thick Plexiglas acrylic plastic disk. The camera lens then looks through at the reflector, and the shadow of the support rod is completely contained within the image of the camera body. Some rather unusual photographs are possible with this arrangement. The camera appears to hover in the sky over the center of the field. This system is compact, has minimum amount of sky obscuration, and disassembles for easy carrying. (This system is described in more detail on page 69.)

Yet another possibility is an "inside-out Cassegrain" all-sky camera. The camera goes behind the convex mirror and looks through a plastic window. A spacer rod is installed between the center of this window and the middle of a flat secondary mirror. This design is not only free of obscuration from support rods but is also very compact. It is admittedly the most difficult type to construct and also suffers from a bigger central obstruction than the others.

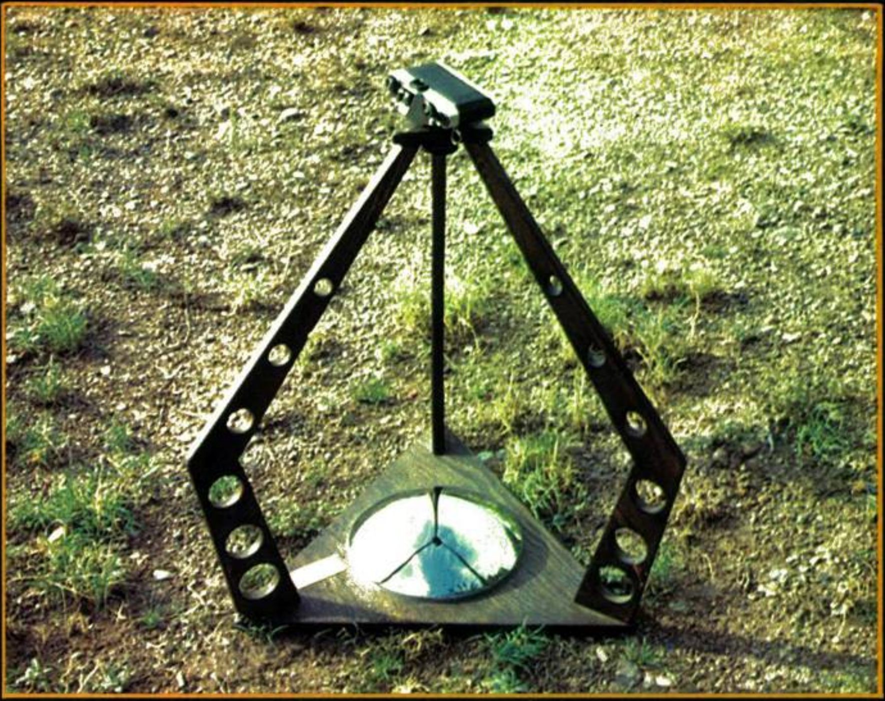
When you begin photographing with your all-sky camera, you will discover that the hubcap mirror dews up on damp nights. You can use a hair dryer to evaporate this moisture — and you won't even mess up the picture if you stay low and off to the side. A more elegant way to solve the dew problem is to install a low-wattage light bulb in the base below the mirror. This keeps the mirror warm and prevents dewing. If you have a glass mirror rather than a hubcap, paint the back black to prevent the light from leaking from tiny pinholes in the silvering.

Using Your All-Sky Camera

One of the beauties of an all-sky rig like this is that you don't need to know a thing about astronomy to achieve exciting



A hubcap, a camera, a tripod, and a towel are all the equipment you need for all-sky photography. The towel keeps grit and dirt from blowing onto the hubcap.



The easy-to-build plywood all-sky rig has proved popular with members of the Saguaro Astronomy Club in Phoenix, Arizona. The camera mount is a metal plate screwed to one side of the triangular top ring; the camera points through the hole in the ring. Photos on this page by Chris Schur.

results. All you have to do is set the all-sky camera system on a level surface and open the camera shutter. It's virtually foolproof. There is no need to even know which constellation to aim at — just aim the device straight up and start the exposure.

How long should you expose? That depends on the usual factors: the brightness of the objects you want to record, the brightness of the background sky, the film speed, and the camera's focal ratio. The effective focal ratio of the all-sky system is approximately that of the taking lens on the camera, so if you're using a 50mm f/2.8 lens to photograph the mirror, the focal ratio of the system will also be f/2.8.

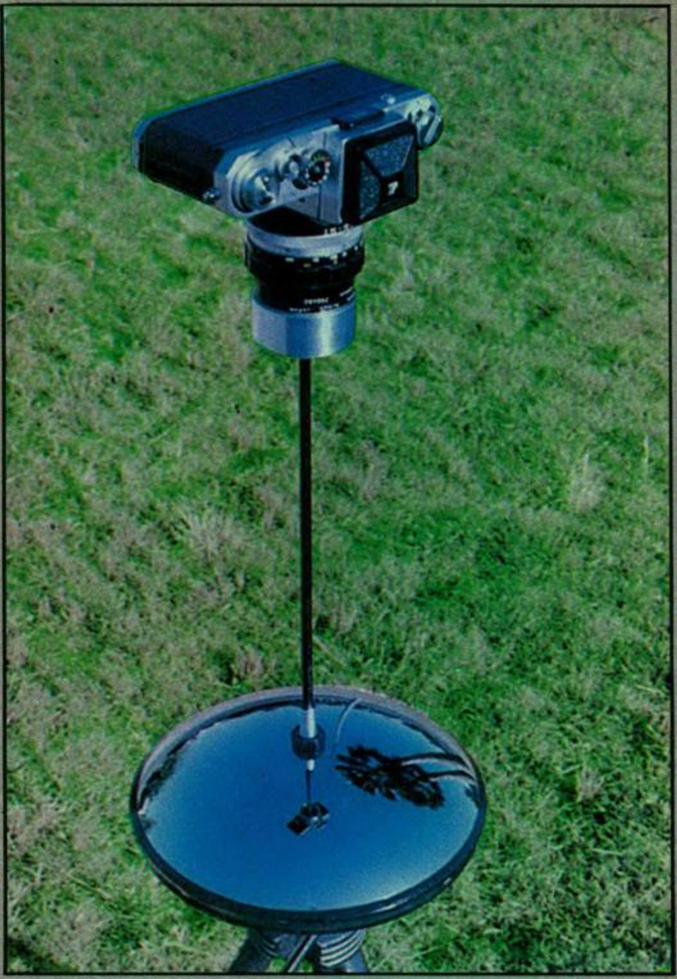
Your have the usual choice of using color or black-and-white films: the film you use depends primarily on the type of subjects to be shot. We have found that fast films such as Fuji HR1600 or Konica 1600 print film, 3M-1000 color slide film, and push-processed Tri-X work well for meteors, aurorae, and the zodiacal light. Slow films such as hypered Kodak Tech Pan 2415 are best for panoramas of the Milky Way and deep-sky object sky surveys where good resolution and low graininess are important. For daytime photos of clouds, rainbows, and other atmospheric and terrestrial subjects, color slide films work the best.

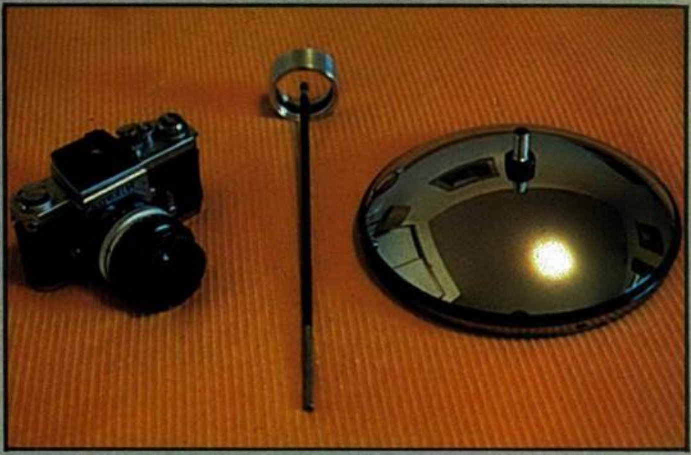
Don't forget to focus carefully, but do not focus on the mirror itself: focus instead on the image of the sky reflected in it. What the camera sees is called a "virtual image." As far as the camera is concerned, this image is behind the convex mirror. Since stars may be too faint to see in the camera's focus screen, focus during the day on a distant object. Carefully note the exact focus setting and then reset the lens to the same focus at night.

When you view the images taken with this type of rig, the first thing you will notice is that the sky is backward. This occurs because you have photographed the image reflected in a mirror. When projecting transparencies or printing negatives taken with an all-sky mirror, flip the negative or transparency from the normal position. This will re-reverse the image of the sky.

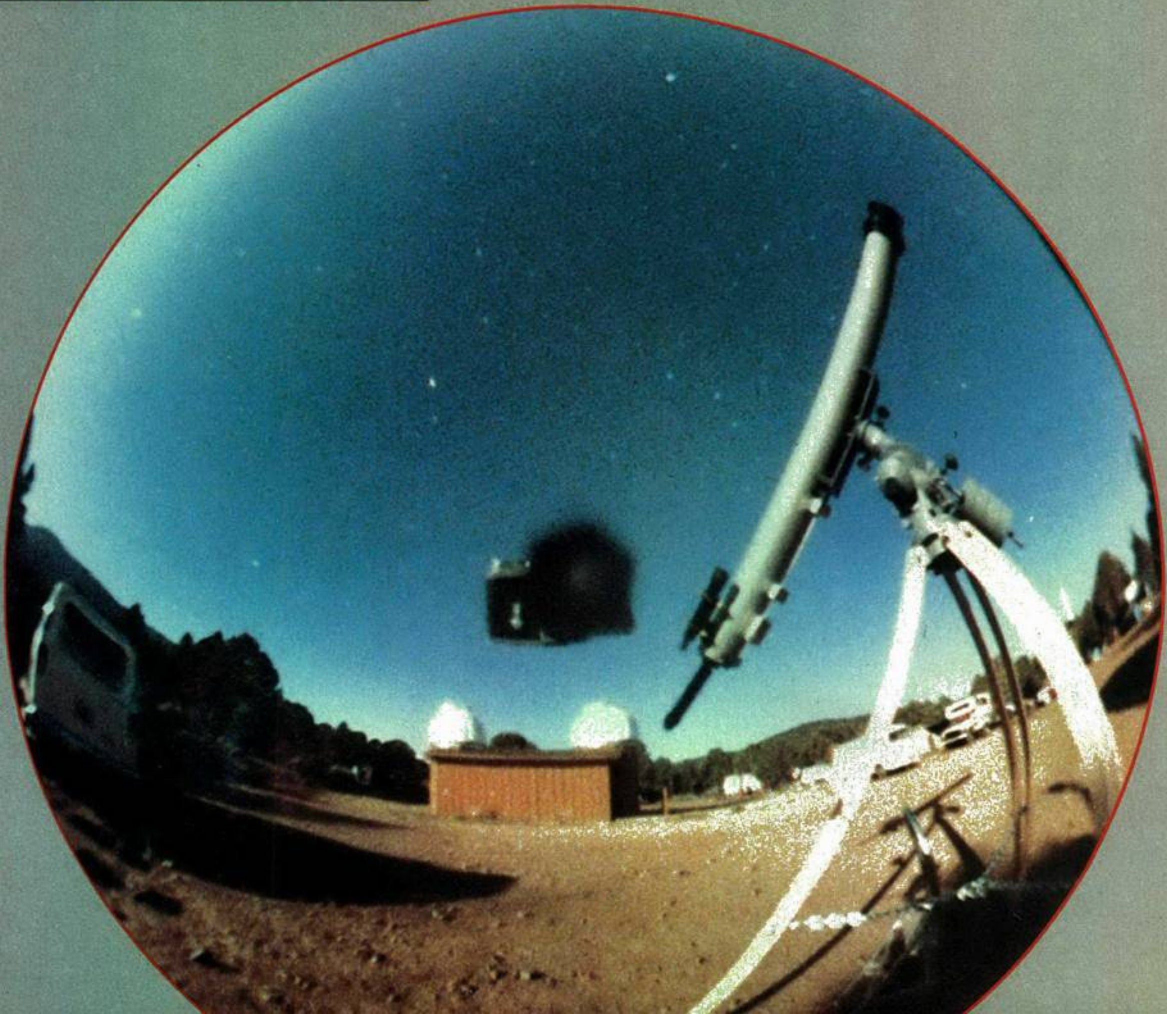
Tracking exposures to eliminate star trails is also possible, though at first glance it would seem difficult to mount a bulky all-sky system on an equatorial mount. We have found that most 4-inch or larger Newtonian and Schmidt-Cassegrain telescopes can serve as tracking platforms.

Point the telescope toward the zenith and then mount the all-sky system on the front of the telescope. This arrangement is reasonably stable for five to ten degrees on either side of the zenith. Bungee cords or clamps hold the base on the front of the tube and may help calm your fears of a sudden crash.





Assembled (left) and knocked-down (above) views of the strutless all-sky camera design by Jeffrey Charles show how simple and how portable an all-sky camera can be. The night photo (below) is a 2-minute exposure on Ektachrome 400, taken at the 1986 Riverside Telescope Maker's Conference. The Full Moon provided illumination.



Materials

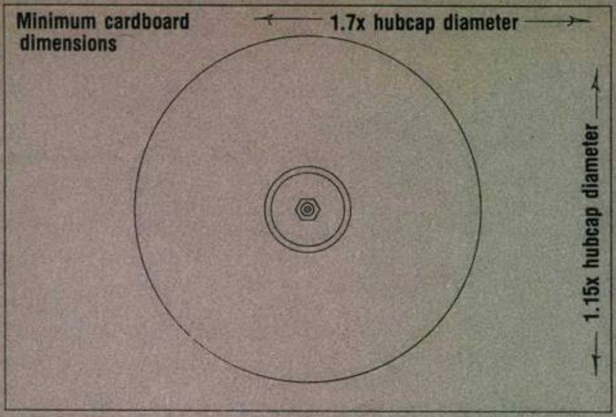
- 9" diameter spherical hubcap
- 4" of specified threaded rod (see table below)
- Four nuts to fit threaded rod
- 1.5" or 2" pipe-end cap
- Drill rod specified (see table)
- 2.5" square of 3/4"-thick Plexiglas
- Filter adaptor for your camera lens (for filter 3mm to 6mm larger than lens threads)
- 11" x 17" black poster board
- Black paint
- Adhesive

Tools

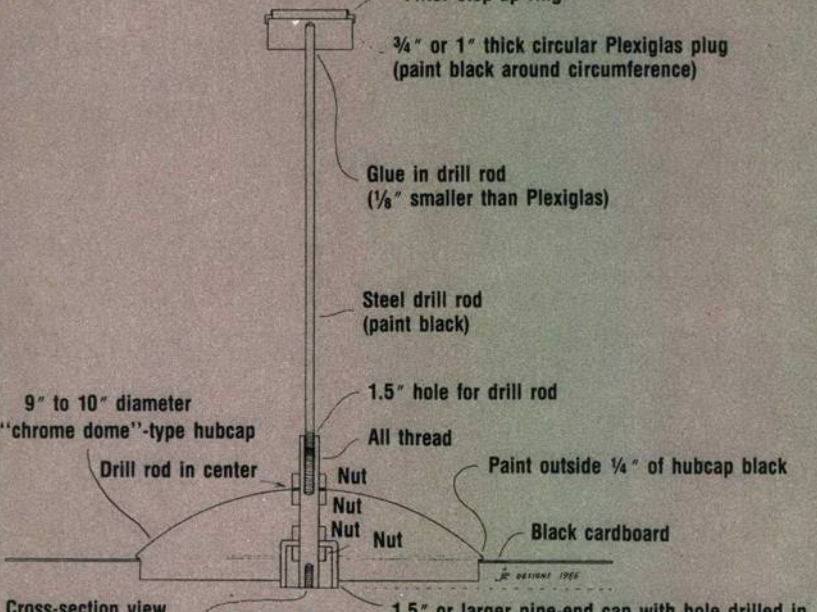
- Electric drill or drill press
- Coping saw or band saw
- Hack saw with fine-tooth metal-cutting blade
- Vise
- Fine and medium files, sandpaper
- 13/64" drill bit
- Drill bit, diameter of drill rod
- Drill bit, diameter of threaded rod
- 1/4"-20 tapered tap
- Razor blade or large scissors
- Compass and pencil

Threaded Rod and Drill Rod Sizes

Lens	Threaded rod	Drill rod
28mm	1/2"-13 x 4"	7/32" x 9.75"
35mm	1/2"-13 x 4"	1/4" x 12.25"
50mm	5/8"-11 x 4"	5/16" x 17.75"
55mm	5/8"-11 x 4"	3/8" x 19.5"


Minimum cardboard dimensions
1.7x hubcap diameter
1.15x hubcap diameter

Top view


Filter step-up ring
¾" or 1" thick circular Plexiglas plug (paint black around circumference)
Glue in drill rod (⅛" smaller than Plexiglas)
Steel drill rod (paint black)
1.5" hole for drill rod
9" to 10" diameter "chrome dome"-type hubcap
All thread
Drill rod in center
Nut
Nut
Nut
Nut
Paint outside ¼" of hubcap black
Black cardboard
Tap ¼"-20
1.5" or larger pipe-end cap with hole drilled in center

Cross-section view

The Strutless All-Sky Camera

by Jeffrey Charles

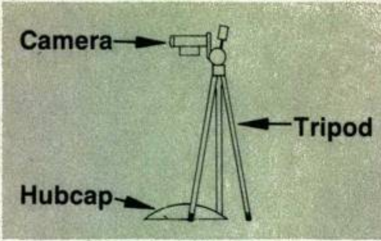
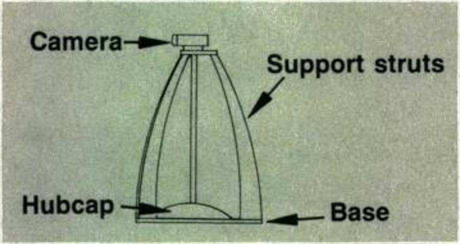
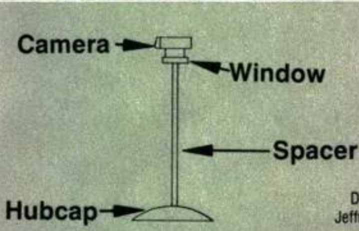
This design allows you to shoot all-sky pictures without any annoying camera-support struts. The "backbone" of the design is a 4" length of threaded rod that holds the base, the reflector, and the camera support rod together. Consult the accompanying table for the diameter of this piece. In the bottom end drill and tap a hole for ¼"-20 threads. This hole will allow you to attach the all-sky camera to a tripod or to mount it on a telescope for tracking. In the top end drill a hole 1½" or more deep to accept the drill rod. Make a base for the unit from a pipe-end cap of either metal or heavy plastic. Drill a hole in the cap for the threaded rod; then jam a nut on either side. If you use a reducing adaptor, you can simply clean up the threads with a large tap. This base provides support when you mount the completed all-sky camera.

The hubcap, like the end-cap base, is mounted on the threaded rod through a hole in the rod's center. When you drill this hole, take care not to bend the hubcap with too much pressure. (When you're drilling, a block of soft wood behind the center of the hubcap can prevent bending.) Mount the hubcap between two nuts on the threaded rod.

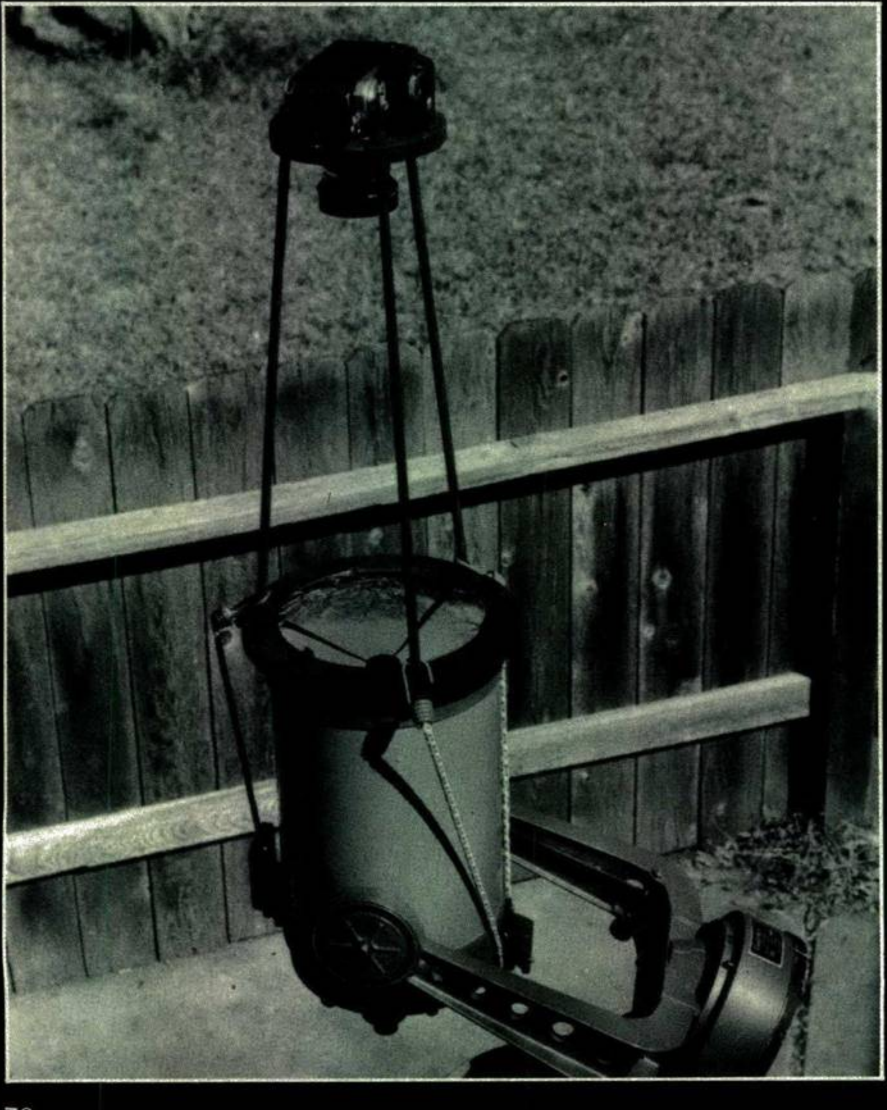
To hold the camera, purchase a "step-up" filter thread adaptor ring from a camera store. This device will have male threads to fit your camera lens at one end and female threads for an oversize filter in the other. Cut a circle of ¾"-thick Plexiglas with three evenly spaced humps $^1/_{32}$" to $^1/_{16}$" high around its circumference and drill an accurately perpendicular hole ⅝" deep for the drill rod. (While you're doing this, leave the protective paper covering on the Plexiglas to prevent scratches.)

The body of the plug must be just small enough to fit into the front of the step-up ring, but the humps should prevent it from entering. With two humps inside the ring, the third should be about 0.015" too high to fit in. File a 20-degree taper about ⅛" wide on each hump and then try to force the plug into the step-up ring. If it won't fit, file just a little more off the top of each hump and try again. Peel the protective paper off the Plexiglas and apply adhesive to the adaptor ring before threading the plug into place for the final time. Glue the plug into the adaptor ring.

When using this all-sky reflector, place a sheet of black cardboard or ⅛" Masonite behind the hubcap. This will eliminate distracting backgrounds outside your all-sky circle.

Type	Configuration	Advantages	Disadvantages
Camera on tripod		Simple	No tracking Tripod visible
Support struts		Stable Easy to build Easy to track	Bulky Struts visible
Strutless		Compact Strut invisible Easy to track	Difficult to build

Drawings by Jeffrey Charles



Want something better than star trails? Fasten your all-sky camera to the front of a telescope and let the telescope's drive do the work. The photo on page 66 was taken with this all-sky rig. Photo by Robert Reeves.

Try exposures up to 30 minutes. Since the all-sky rig is sitting on top of the capped end of the telescope, no guiding is possible. If the polar alignment of the scope is reasonably good, the image scale of the extreme wide-angle view will mask tracking errors.

That's all there is to building and using an all-sky camera. Next you need to apply your imagination to "seeing" potential pictures. It is unfortunate so many beautiful sky phenomena go unphotographed simply because they are so big they don't fit inside the fields of view you get with ordinary photo equipment. Nowadays, especially, there are lots of interesting opportunities and so many films and advanced processing techniques available. With an all-sky setup so inexpensive and simple to construct, there's no longer any reason to neglect the beauty of the whole sky.

Jeffrey Charles, inventor and amateur astronomer, is the proprietor of Versacorp, a small firm that makes the VersAgonal Series 2 "SCT enhancer" and other accessories. Chris Schur is an avid astrophotographer who operates the Black Canyon Observatory. Both are members of the Saguaro Astronomy Club in Phoenix, Arizona. Astrophotographer Robert Reeves contributed "In Search of Dark Nebulae" to the December 1986 issue of ASTRONOMY and "Photographing the Northern Milky Way" to the Winter 1986 issue of Deep Sky.

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ASTRONOMY
Reviews

Polarized Light in Nature

G. P. Konnen
172 pages, cloth, no price given
Cambridge University Press (1985)

Polarized Light in Nature is an encyclopedic search for any natural processes that produce light with some degree of polarization.

This search does turn up some interesting processes; the most familiar process is the polarization resulting from the scattering of light that causes our blue sky. Also mentioned is the claim that around 1000 A.D. the Vikings discovered the polarizing properties of some types of minerals and used these properties as a navigational aid when the Sun lay hidden by clouds. With a "sunstone" (probably a cordierite crystal) they could infer the direction of the Sun from the polarization of a small patch of blue sky. The method may have been even more useful where the sky retains its pattern of polarization in fog or a thin overcast.

Most of the processes that produce polarization result from reflection or scattering, and many combinations of these two effects exist in the atmosphere and on Earth's surface. A few basic principles govern polarization processes, and these principles are relatively easy to understand once they are thoroughly explained. However, I suspect that the book's introductory discussion of how polarization works will be inadequate for those without any background in the subject.

Particularly interesting is the book's coverage of rainbows. A rainbow is strongly polarized in a direction tangential to its arc, and the polarization results from the internal reflection of sunlight inside water droplets. The brightness one sees inside the arc of a primary rainbow is the result of light rays taking similar paths through drops of water. If this happens with very small drops of water, diffraction effects become important, because they broaden the bow and cause the dispersed colors to overlap. This overlapping produces a wide white bow, commonly called a fogbow, or cloud-bow.

Konnen points out that the tangential polarization of this cloud-bow and the brighter sky inside are still present. He concludes: "So with the aid of a polarizing filter, everybody can easily observe the cloud-bow. Strange to relate, rainbows can be seen almost every day, though merely in the form of the inconspicuous cloud-bow."

Few astronomical objects show strong polarization effects. The only examples discussed in the book are cometary tails, the solar corona (both resulting from single scattering of sunlight), and two objects that emit polarized light. One of these is the Crab Nebula in Taurus and the other is the jet coming from the elliptical galaxy M-87 in Virgo. The polarized light emitted by these objects results from synchrotron radiation — the energy of relativistic electrons following spiral paths inside strong magnetic fields.

Most of the polarization effects we see in our environment involve linearly polarized light. The only examples of circularly polarized light Konnen identifies are metallic reflections of previously polarized light and the reflections from the shells of beetles from only one family, the *Scarabaeidae*.

This book is a thorough search of nature for any manifestations of polarized light, and if you want to learn about the subject, this is the book. *Robert Greenler.*

Big and Bright: A History of the McDonald Observatory

David S. Evans and J. Derral Mulholland
186 pages, cloth, $19.95; paper, $9.95
University of Texas Press (1986)
[publisher's address: Box 7819, Austin, TX 78713]

If you ever want to endow an observatory, first make darn sure you leave all your relatives well-provided for. Or else shell out the money long before any of them can stop you on grounds that you've lost your mind. William J. McDonald, a well-to-do bachelor banker from east Texas, had done neither when he died at age 81 in 1926.

McDonald, who developed an interest in astronomy in middle age, left an estate worth about $1.6 million, roughly $6 million in today's money. After bequeathing $15,000 each to most of his relatives (he had two brothers, both with large families), the bulk of the estate — about $1 million — was given to the University of Texas for the establishment of an astronomical observatory. The contents of the will were a total surprise to everybody involved. The university was naturally pleased; McDonald's relatives were not and promptly hired lawyers. Three years later the university and the heirs finally reached an out-of-court settlement that stopped a fiscal hemorrhage (five trials, hearings, and appeals) threatening to destroy the entire estate.

The bequest had taken the university by surprise partly because the university had as yet no astronomy department! Coincidentally, many of the staff at Yerkes Observatory, run by the University of Chicago and situated in southeastern Wisconsin, had decided Yerkes needed an outstation in a better climate. In addition, a larger telescope than the famous 40-inch refractor was required if the observatory was to continue contributing to the growth of astronomy. (The 100-inch reflector on Mount Wilson in southern California had established in one stroke the necessity for siting large instruments in locations that offer clear, dark skies and good seeing.) Among the locations scouted by the Yerkes astronomers was Texas. In retrospect, the outcome seems almost foreordained: the University of Texas had the money for an observatory but no staff; Chicago had staff, but no observatory. Luckily, the resulting marriage of convenience has proved generally satisfactory.

Surveys of potential locations for the as-yet unbuilt McDonald Observatory soon narrowed the choice to a relatively flat-topped peak in the Davis Mountains of west Texas. The nearest town, sixteen miles away by road, was Fort Davis, the county seat. Established as an Army post in 1854 at the junction of the Chihuahua Trail and the Butterfield Overland Mail stagecoach route, Fort Davis had a population of several hundred at the time the observatory was erected. (The population is only about eight hundred today.) The peak, soon renamed Mount Locke to honor the grandfather of the woman who gave it to the university, is 6,800 feet high. Telescopic tests of the seeing and transparency confirm that this is one of the best sites in North America for astronomical observations. Its remoteness even today protects it from the light-pollution problems that have afflicted so many observatories once thought to be sited well beyond the clutches of civilization.

But in 1934, with the new joint agreement barely signed, Yerkes and McDonald director Otto Struve faced a problem. The design for the main instrument of the new observatory called for an 80-inch, f/4 telescope that could operate at prime, Cassegrain, or coude foci (Newtonian focus was skipped to save money) and would be equipped with a battery of assorted photometers and spectrographs to exploit its great light-grasp to the fullest. But construction of the telescope, destined to be the world's third largest after the Palomar 200-inch (which was just starting to be built) and Mount Wilson's 100-inch, would take several years. Struve, an intense and dedicated man and the fourth-generation astronomer in his family, wanted publishable astronomical results right away.

Accordingly, in the autumn of 1934 he sent young astronomer Franklin Roach to Mount Locke with a small telescope for measuring the night sky brightness. Later Struve shipped a 12-inch refractor that was used for variable star photometry. Eventually other observers trickled in, bringing more instruments and making do with the still-primitive facilities. While the main scope's dome and service buildings were being constructed, astronomical research got underway and the population of the tent-city on the mountaintop grew.

Meanwhile, the 80-inch main instrument was plagued with delays, which caused innumerable headaches for the astronomers and for Warner & Swasey, the Cleveland firm that was building it. Although the design for the cross-axis mounting contained several innovations, the snags centered on the optics. To mention just one problem, the mold stretched as the main mirror was poured, so the telescope became an 82-inch. (Luckily the tube of the telescope, already built, had room to spare.) The biggest problem, however, was that the optician in charge, though highly experienced with refractors, was dealing with his first large mirror. Besides working under marginal conditions, he misunderstood what the standard Foucault test showed about a mirror. He would then use an incorrect process to "correct" what he thought were the errors of figure. As a result the mirror never advanced beyond a fairly crude state. Real progress came only when an exasperated Struve, fed up with what seemed like endless delays, insisted that the head optical technician from Yerkes supervise the project.

Finally, however, the mirror was finished and installed. On May 5, 1939 — though observations had been carried out for a few months already — the 82-inch telescope was officially "opened" and handed over to the University of Texas in a grand dedication ceremony cum scientific symposium attended by the most notable astronomers in the world. (In a used bookshop now and then you can still unearth copies of the elaborate souvenir book Warner & Swasey printed for the occasion.) It was the last such gathering for nearly a decade because World War II broke out in Europe only four months afterward.

Authors Evans and Mulholland are both long-time McDonald astronomers, and this enjoyable history benefits greatly from a richness of anecdote that could only be compiled by insiders. Along with rum-

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maging in dusty archives, they seem to have interviewed just about everyone who ever worked there!

Although McDonald has been overshadowed to some extent by Palomar's great fame — and Mount Wilson's late notoriety — McDonald has in recent years regained much public notice through its highly acclaimed and widely heard "Star Date" programs. Among astronomers, of course, McDonald has always been known as a mecca. The authors note that after the war, "anyone who was anybody in world astronomy" was either on staff or observed there. Among the more noted results of the observatory were Gerard Kuiper's discovery that Titan, Saturn's largest moon, had a methane atmosphere. This was the first detection of an atmosphere on any satellite in the solar system. (At McDonald, Kuiper also discovered Miranda, the fifth satellite of Uranus, and Nereid, Neptune's second moon.) Other important research included Thornton Page's discovery that the motions of galaxies showed they were far more massive than their luminosities implied — a result that is still unexplained today.

If I have any criticism of the book, it's that Evans and Mulholland chose to end their story in 1969 with the dedication of the 107-inch telescope, built for NASA-sponsored solar system research. The authors explain that this marks the point in time when the telescope built under the original McDonald bequest was finally surpassed in size. To bring the narrative up to date they provide a lengthy epilogue surveying the work and changes since 1969. This period saw McDonald grow to become an astronomical research observatory par excellence. Unfortunately, the epilogue's coverage is skimpy compared to the quality of work done. Evans and Mulholland confess that doing justice to recent history is probably impossible at this point. It's too recent and, more importantly, it would tend to overshadow the story of the founding.

Big and Bright is anecdotal history at its best. In fact, I wish there were more stories. (At times the epilogue can turn annoyingly coy. Well, what *did* happen with the Swiss Army knife? And the backsliding firetruck?) Perhaps because the principals are now dead, the authors are more forthcoming with older anecdotes. One concerns the astronomer George van Biesbroeck. Rather short in stature, he was unable to operate the camera at the prime focus of the 82-inch when he stood behind the safety rail of the dome scaffolding. Therefore he habitually climbed up onto the rail and leaned out over thin air, catching himself on the telescope 45 feet above the steel-plate floor — in the pitch dark, of course. (Not to keep you in suspense, Dr. van Biesbroeck lived into his nineties.) While these may be just well-chewed old rags to anyone immersed in the social culture of astronomy, we outsiders don't often get such a look behind the scenes.

I recommend the book to anyone who wants to see what it takes to get a major institution going from scratch. You won't learn any astronomy, but this book will provide you with an interesting evening or two of reading. If your local bookstore can't or won't get it for you, send a check (plus $2 for shipping) to the University of Texas Press. *Robert Burnham.*

Air: Composition and Chemistry
Peter Brimblecombe
224 pages, cloth, no price given
Cambridge University Press (1986)

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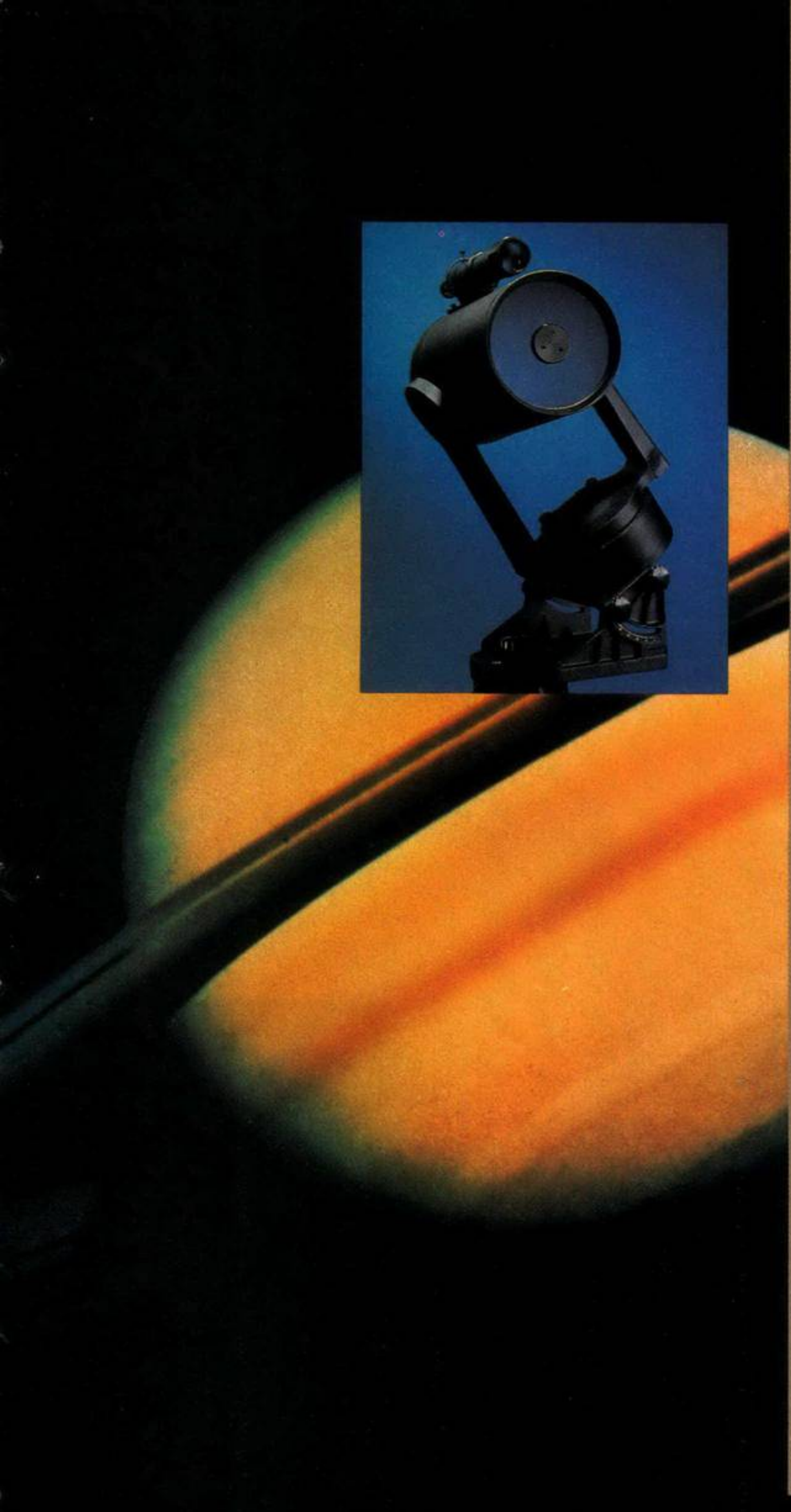

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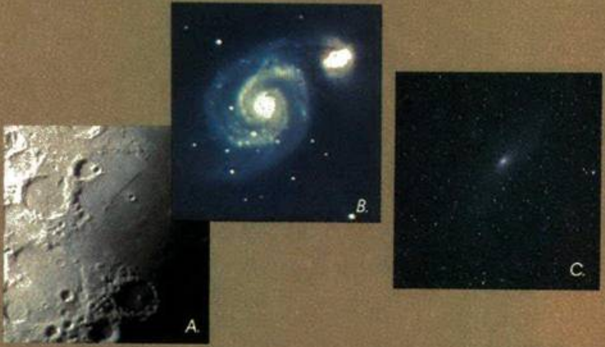

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B. *Galaxy M-51 taken by Dr. Stephen Kent of Harvard University with the Bausch & Lomb 8" Schmidt/Cassegrain and a C.C.D. Exposure time — 10 minutes!*

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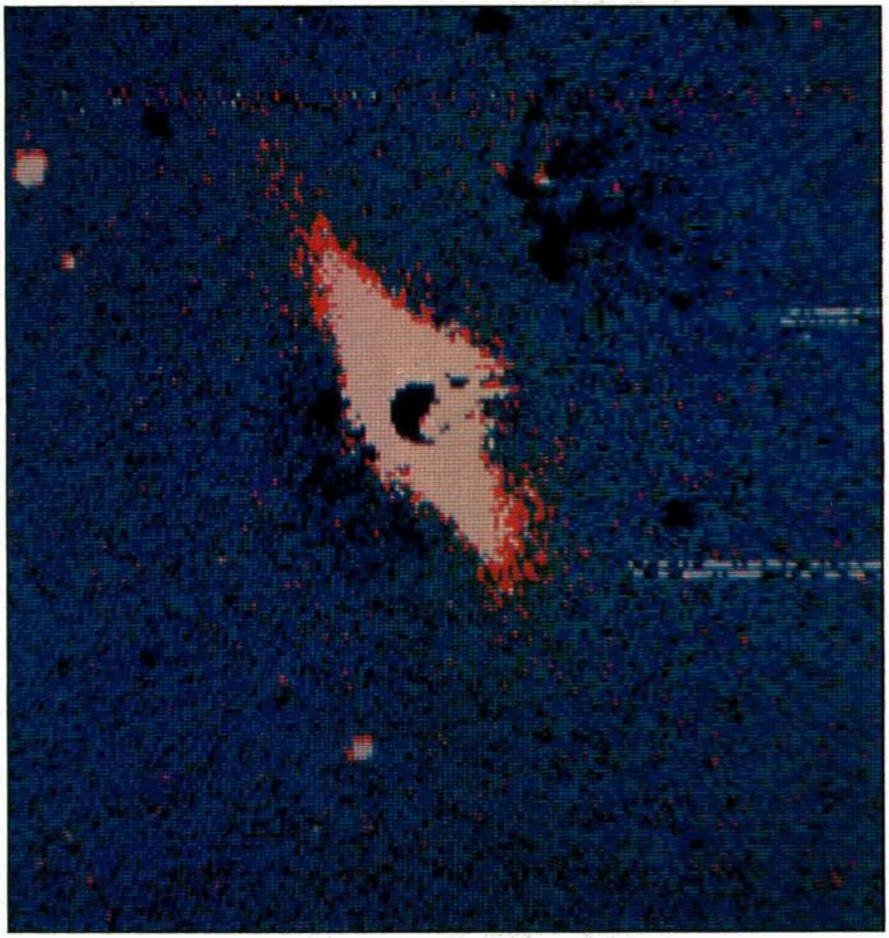
AstroNews

SPECIAL REPORT

The 169th Meeting of the American Astronomical Society

Pasadena, Calif. — Over 1,500 astronomers from around the world gathered here for the 169th meeting of the American Astronomical Society from January 4 to 8, 1987. The meeting, which was the largest in the society's eighty-eight year history, was hosted by three major astronomical institutions based in Pasadena: the Mount Wilson and Las Campanas Observatories of the Carnegie Institution of Washington, the Jet Propulsion Laboratory, and the California Institute of Technology.

Galactic evolution, new ground-based telescopes, the origin of quasars, and the future of NASA's space science program were some of the topics presented in the four days of invited lectures, papers, and press conferences. This month's Astro-News *highlights the meeting's major findings and reports.*



The disk of dust around Beta Pictoris may be a planetary system in formation. Using a stellar coronagraph, astronomers blocked the light of the star to produce this infrared image of the disk. Photo by Ben Zuckerman and Harland Epps, UCLA; Jon Gradie and Joan Hayashi, University of Hawaii; and Robert Howell, University of Wyoming.

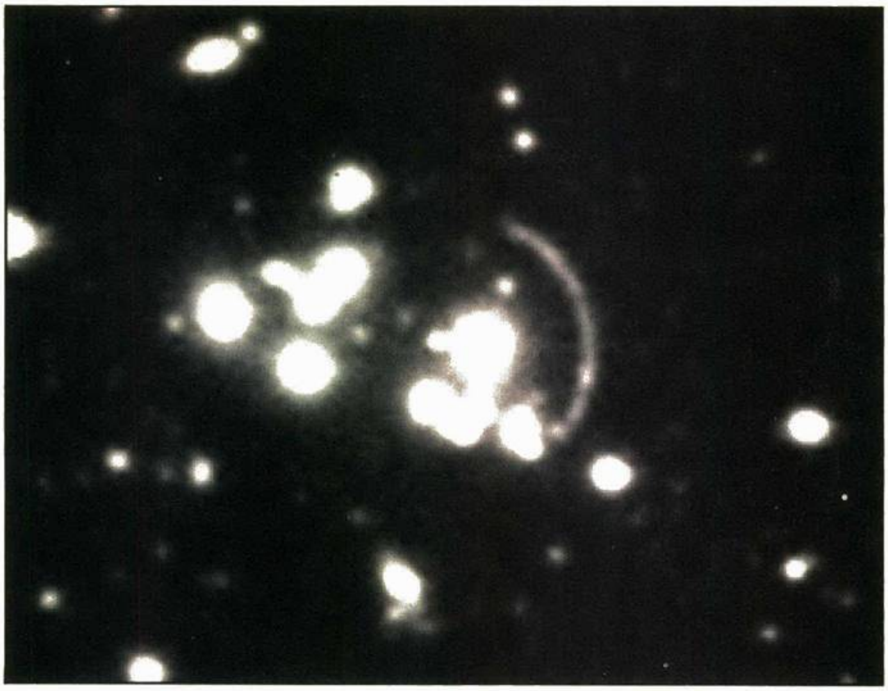
Young Solar Systems around Other Stars

What may be planetary systems in the making — disks of gas and dust orbiting young stars — was the subject of two separate studies presented at the AAS meeting. Observations of HL Tauri and Beta Pictoris revealed that the disks of matter circling the two stars have properties similar to what astronomers believe were the conditions in our early solar system.

The HL Tauri observations, made by Anneila Sargent of the California Institute of Technology and Steven Beckwith of Cornell University, show a disk of gas orbiting the star in much the same way planets in our solar system orbit the Sun. According to the laws of planetary motion established by Johannes Kepler in the seventeenth century, planets near the Sun orbit faster than those farther away. The astronomers found that HL Tauri's gas disk also obeys Kepler's law: the gas velocities in the disk increase nearer the star.

The existence of a disk of gas moving in this pattern around a very young star like HL Tauri, which is less than 1 million years old, is considered strong evidence that the conditions for planetary evolution can exist around other stars.

Observations of a flattened disk composed of relatively large solid particles provide the evidence for a planetary system around Beta Pictoris, another relatively young star (1 billion years old) by our Sun's standard (almost 5 billion years old). This finding, made by Christopher Burrows and Francesco Paresce of the Space Telescope Science Institute in Baltimore, may indicate that the process



of planet formation has begun in the disk.

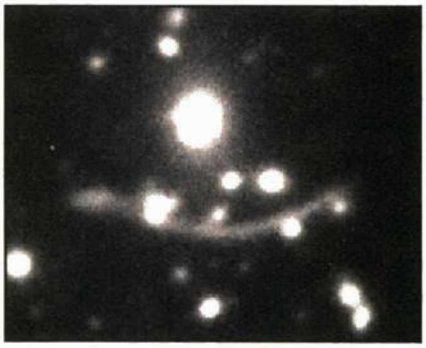
Using the 2.2-meter telescope at the European Southern Observatory in La Silla, Chile, Burrows and Paresce produced a precise visible-light image of the Beta Pictoris disk — a highly flattened disk three times the diameter of our solar system. Spectral analysis of the light reflected by the disk revealed that it is made up of particles at least ten times larger than interstellar dust.

According to Paresce, "The observations show unequivocally that an agglomeration process is in an advanced state, where fine interstellar grains stuck together to form larger clumps." The observations do not reveal, however, whether this process has formed objects any larger than very small pebbles. The astronomers plan to continue their investigations of Beta Pictoris with the Hubble Space Telescope.

Luminous Arcs Discovered in Clusters of Galaxies

While conducting a study of the surface brightnesses of giant elliptical galaxies in clusters of galaxies, Roger Lynds of Kitt Peak National Observatory and Vahe Petrosian of Stanford University inadvertently photographed the largest structures astronomers have ever seen at visual wavelengths.

The bright, curved structures are 100 kiloparsecs long — five times larger than the diameter of the Milky Way Galaxy. The three arcs were discovered in the clusters known as Abell 370, Abell 2218, and cluster 2244-02. They appear to be concentric with the supergiant elliptical, of cD, galaxies at the center of the clusters. One of the arcs appears relatively smooth but another is broken into knots and clumps. The observations were made with the 4-meter telescope at Kitt Peak.



Just what are these immense, bright arcs discovered in the clusters of galaxies known as 2242-02 (top) and Abell 370 (above)? At this point astronomers can only speculate. National Optical Astronomy Observatories photos.

The data available on the arcs does not provide a clear understanding of these unique objects. Their blue color indicates recent star formation, but this doesn't explain their precise geometric shape. Their apparent association with the cD galaxies may mean they are byproducts of the violent merging of galaxies that produces these supermassive galaxies.

"We can only guess what goes on here," reports Petrosian, who hopes planned observations at radio wavelengths will resolve some of the many outstanding questions. "At the moment we're having fun trying to figure them out."

U.S. Space Science Program in Jeopardy

The governing body of the American Astronomical Society voiced concern

The Galaxy and the Solar System

Roman Smoluchowski, John N. Bahcall, Mildred S. Matthews, Editors

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and the
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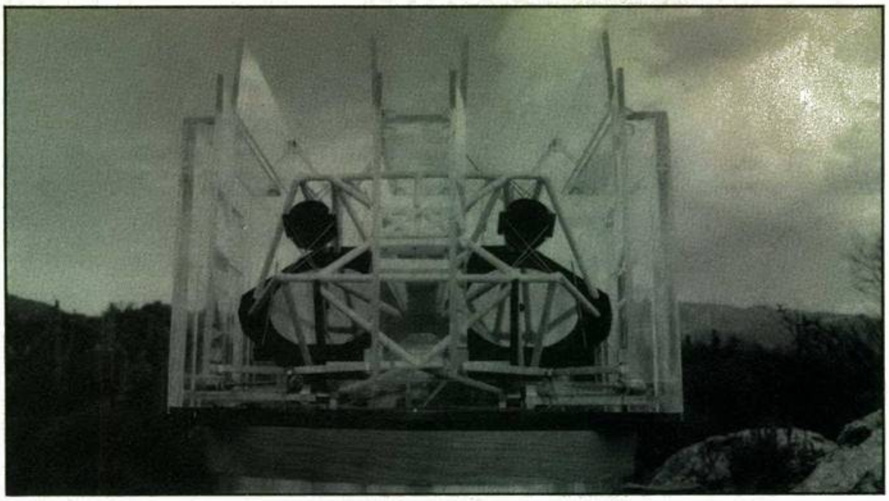


Large telescopes were a big topic at the AAS meeting. Among the projects discussed were the 11.3-meter binocular Columbus Project (above), one of the four telescopes planned for the Mount Graham International Observatory in Arizona; the proposed upgrade of the Multiple Mirror Telescope from six 1.8-meter mirrors to a single 6.5-meter mirror; and the 10-meter Keck Telescope, which is under construction in Hawaii and on schedule for opening in 1990.

about the future of the United States' space science program in a resolution passed during the Pasadena meeting. The AAS called on NASA to "initiate a program of major missions in space astronomy, planetary exploration, and solar astronomy as components of a preeminent U.S. space science program."

By the time the Shuttle is ready to fly in 1988, the U.S. will have been without a launch capability for more than two years. According to the resolution, "this hiatus has seriously jeopardized the timely and vigorous conduct of space science in general, and space astronomy in particular." It cites several specific concerns:

- "The Hubble Space Telescope and the Cosmic Background Explorer missions, currently in prospect, have suffered costly delays."
- "Several major flight-ready missions including Galileo, Ulysses, and ROSAT are seriously threatened by continued and costly delays in their launching."
- "No planetary discovery missions to either large or small bodies have been launched by the U.S. in over a decade."
- "The viability of numerous, meritorious, high-priority major missions including the Space Infrared Telescope Facility (SIRTF), Advanced X-Ray Astrophysics Facility (AXAF), High Resolution Solar Observatory (HRSO), and second generation [Space Telescope] instrumentation is seriously jeopardized by the permanent loss of flight opportunities."
- "The loss of flight opportunities is stifling the field of space science and threatening to erode the United States' outstanding technology and scientific manpower base in space science and astronomy."

The resolution proposes that NASA "pursue the development of a mixed fleet of launch vehicles" to increase the number of flight opportunities and to avoid another extended breakdown in the space program caused by reliance on a single launch system.

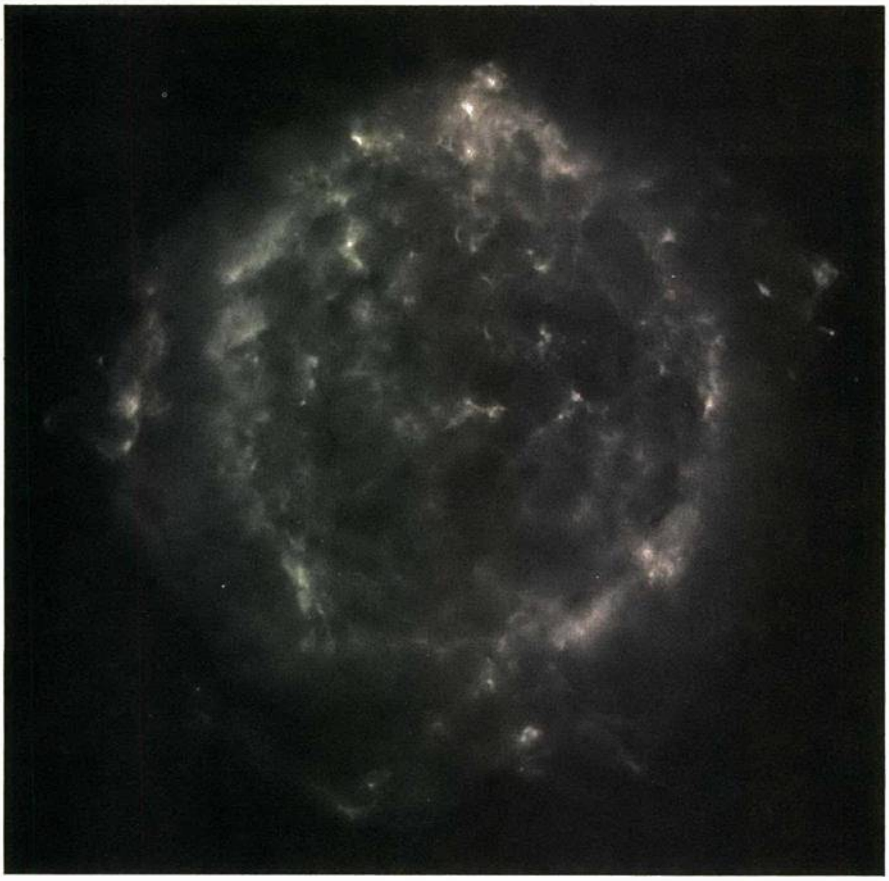
Bright Infrared Galaxies May Be Young Quasars

Intensely luminous galaxies emitting radiation at infrared wavelengths may be quasars at an early stage of development, according to astronomers at the California Institute of Technology and the University of Massachusetts. Their research also suggests that galactic collisions may be responsible for the highly concentrated energy sources that power quasars.

Quasars, the most luminous objects in the universe, generate an immense amount of energy, primarily at optical and ultraviolet wavelengths. The ten infrared galaxies studied in this research emit the same total energy as quasars, but 99 percent of it is at infrared wavelengths. This is apparently due to the absorption of the visible light by a dust shell surrounding the central energy source, which is then re-radiated at infrared wavelengths.

This unusually large output of energy is just one link between quasars and these galaxies, which were first detected by the Infrared Astronomical Satellite. The spectra of the infrared galaxies are similar to those of quasars and other "active" galaxies.

According to David Sanders of Caltech, one of the nine astronomers who worked on this research, "The evidence from the optical spectra also suggests that the ultraluminous IRAS galaxies are undergoing a 'housecleaning' process, in which the intense luminosity of the energy source has started to disperse its obscuring dust shroud. Our data indicate that as this process continues, the infrared galaxies will begin to display the properties of



High-resolution radio images of supernova remnant Cassiopeia A reveal that most of the material from the stellar explosion is thrown off as distinct fragments that puncture the smoothly expanding shell. The craterlike structures visible in this image were made by fragments four hundred times larger than the solar system. The research, which used images from the Very Large Array radio telescope, was presented by Robert Braun and Rick Perley of the National Radio Astronomy Observatory in New Mexico and Steve Gull of the University of Cambridge. NRAO photo.

optically brilliant quasars."

Observations at radio wavelengths show that these galaxies have tremendous supplies of molecular gas and dust that is being funneled toward their centers. The distribution of gas in one of these galaxies, Arp 220, shows a high concentration of gas in its central region. This funneling of ample "fuel" to a small central area could be the cause of the quasar's brilliance.

"One of the major unanswered questions about quasars is how they acquire and process enough fuel to shine so brilliantly," said Sanders.

The collision of two spiral galaxies may provide part of the answer. Photographs of the infrared galaxies taken at Palomar Observatory show the characteristic disturbed disk and double "tidal tail" of a galactic merger.

Finding Galaxies behind the Milky Way

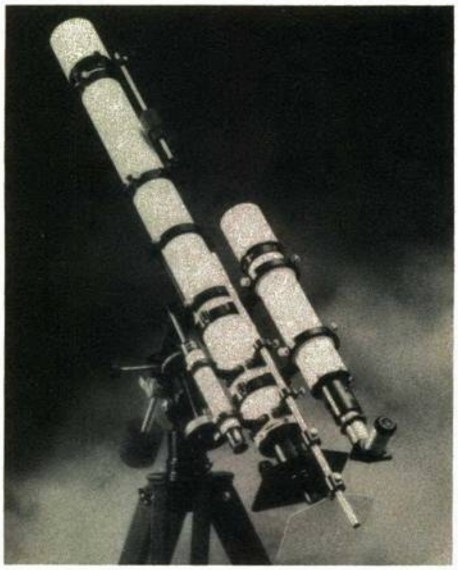
About one-quarter of the sky, the area occupied by and immediately surrounding the Milky Way, has been effectively closed to astronomers searching for galaxies — until now. A pilot study using the National Radio Astronomy Observatory in Green Bank, West Virginia, has discovered ten galaxies hidden in this "zone of avoidance" and identified their types.

Frank Kerr and Patricia Henning of the University of Maryland made test observations of this area at the 21-centimeter spectral line produced by interstellar hydrogen atoms, which allowed them to see through the clouds of dust in the plane of the Milky Way. They identified five spiral galaxies and five irregular galaxies.

Three Studies Find Longer Solar Cycle

The conventional picture of the solar cycle — an 11-year period of solar activity related to increased sunspot activity in the lower latitudes of the Sun — is only a part of an 18- to 22-year global cycle of activity, according to three independent studies presented at the AAS meeting.

The studies, presented by Richard Altrock of the Air Force Geophysics Laboratory, Herschel Snodgrass of Lewis and Clark College, and Peter Wilson of the California Institute of Technology, conclude that a cycle of magnetic and velocity activity begins every 11 years on the Sun



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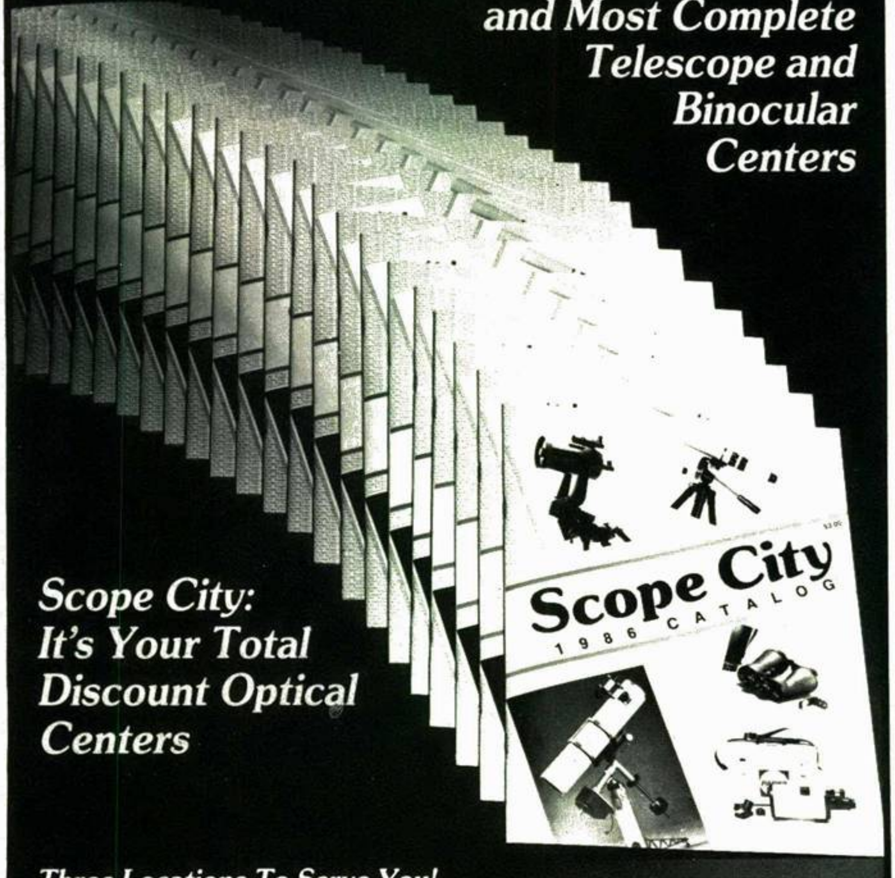

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near the poles and lasts for 22 years. Consequently, there are always two overlapping cycles of activity on the Sun.

The presence of two simultaneous cycles "has to have some basic impact on our understanding of how the Sun, and other stars, work to produce cycles of activity," according to Altrock. Many current models of solar activity are based on the assumption that there is a single cycle.

Using data collected over the last twenty years at Mount Wilson Observatory, Snodgrass concluded that the torsional oscillation on the surface of the Sun — the pattern of windlike zones that drifts from the poles to the equator over an 18- to 22-year period — is connected with the sunspot cycle. Snodgrass proposes that both the oscillation and the sunspots are produced by a system of giant circular cells that are within the Sun's convection zone and spin around their east-west axes.

A different area of the Sun — the upper atmosphere, or corona — also provided data on high-latitude activity related to the sunspot cycle. Altrock's research, which used the photoelectric coronal photometer at the National Solar Observatory in New Mexico, followed a cycle of mild activity at 70 degrees solar latitude as it moved toward the equator. The cycle has now reached the middle latitudes where it will merge with the start of the next sunspot cycle, which is just beginning.

A Galaxy Is Born — 12 Billion Years Ago

A cloud of ionized hydrogen gas 12 billion light-years away may be a galaxy in its first stages of development, according to a team of astronomers from the University of California at Berkeley, the Harvard-Smithsonian Center for Astrophysics, and the University of Arizona.

"This is what theoreticians tell you a forming galaxy should look like," said Hyron Spinrad, the Berkeley astronomer whose long-standing search for distant galaxies led to the discovery.

The "protogalaxy," known as 3C 326.1, is one of three hundred bright radio sources the researchers have been surveying. Spectral data obtained from optical telescopes reveal that the ionized gas emissions are one hundred times more luminous than the starlight coming from within the cloud. This indicates that the protogalaxy has not yet formed a large number of stars and is, therefore, very young.

According to S. George Djorgovski, one of the Harvard-Smithsonian researchers, this discovery raises some problems for current theories of galaxy formation. It is thought that galaxies formed during a relatively brief period very early in the universe's history. A galaxy as old as 3C 326.1 should not be at such an early stage of development, according to these theories.

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24th Space Congress (Space — The Challenge, the Commitment; sponsored by the Canaveral Council of Technical Societies), Cocoa Beach, Florida. Contact: Leslie Neihouse, P.O. Box 1333, Cocoa Beach, FL 32931. Phone: (305) 783-0220.

April 23-25
Middle Atlantic Planetarium Society (annual meeting), Centerport, New York. Contact: Vanderbilt Planetarium, Little Neck Rd., Centerport, NY 11721.

April 24-26
Astronomy Weekend (star parties for beginning and advanced stargazers), Blackwater Falls State Park, Davis, West Virginia. Contact: Pat Northeimer, P.O. Box 490, Davis, WV 26260. Phone: 1-800-CALL-WVA.

April 25
Family Astronomy Day (sponsored by the Custer Institute Astronomy Group), Custer Institute, Southold, Long Island, New York. Contact: Warren Hamburger, 2280 South Grand Avenue, Baldwin, NY 11510. Phone: (516) 223-7878.

April 25
1987 Convention of the North Central Region of the Astronomical League (hosted by the Racine Astronomical Society of Racine, Wisconsin), Racine, Wisconsin. Contact: Elsie Howard, 1505 Windsor Way #3, Racine, WI 53406. Phone: (414) 886-3368.

May 8-August 16
"25 Years of Space Photography" (140 photographs taken by unmanned spacecraft; exhibit organized by the Baxter Art Gallery at the California Institute of Techonology and sponsored by IBM), International Museum of Photography at George Eastman House, Rochester, New York. Contact: Robert A. Sobieszek, 900 East Avenue, Rochester, NY 14607. Phone: (716) 271-3361.

May 9
Astronomy Day Celebration (exhibits, talks, demonstrations, and a star party sponsored by the Northwest Suburban Astronomers), Hoffman Estates, Barrington, Illinois. Contact: Bob Long, 4960 Chambers Drive, Barrington, IL 60010. Phone: (312) 991-7432.

May 9
14th Annual Astronomy Day. Contact: Gary E. Tomlinson, Astronomical League, Chaffee Planetarium, 54 Jefferson S.E., Grand Rapids, MI 49503.

May 22-25
19th Annual Riverside Telescope Makers Conference (sponsored by the Riverside Astronomical Society and the San Bernardino Valley Astronomers), Camp Oaks, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Ave., Riverside, CA 92503. Phone: (714) 689-6893.

May 22-24
1987 Conference of the Royal Astronomical Society of New Zealand. Contact: Conference Registrar, 1987 R.A.S.N.Z. Conference, P.O. Box 2241, Wellington, New Zealand, 6000.

June 12-13
17th Annual Apollo Rendezvous and Telescope Fair (sponsored by the Miami Valley Astronomical Society and the Dayton Museum of Natural History), Dayton, Ohio. Contact: Robert Sponseller, MVAS, 2629 Ridge Avenue, Dayton, OH 45414. Phone: (513) 879-5645.

July 8-11
5th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun (review papers and discussions sponsored by the University of Colorado), Boulder, Colorado. Contact: 5th Cool Stars Workshop, CASA, Campus Box 391, University of Colorado 80309-0391.

July 11-12
National Workshop on Teaching Astronomy for Teachers (graduate credit available, offered during the Astronomical Society of Pacific Annual Meeting), Pomona College, California. Contact: Andrew Fraknoi, Summer Workshop, A.S.P., 1290 24th Avenue, San Francisco, CA 94122. Phone: (415) 661-8660.

July 11-17
Joint Conference of the Astronomical Society of the Pacific, the Astronomical League, and the Western Amateur Astronomers, Pomona College, Pomona, California. Contact: Andrew Fraknoi, Summer Meeting, A.S.P., 1290 24th Ave., San Francisco, CA 94122. Phone: (415) 661-8660.

July 16-24
Space Week '87 ("Space: In Service of Man"). Contact: Jim Harris, Florida Space Society, P.O. Box #291, Sharpes, FL 32959. Phone (message only): (305) 455-3390.

August 20-24
4th Annual Mount Kobau Star Party (observing, telescope-making and astrophotography contests, and speakers), Okangan Valley, British Columbia, Canada. Contact: Peter Kuzel, 4100 25th Avenue, Vernon, British Columbia, Canada V1T-1P4.

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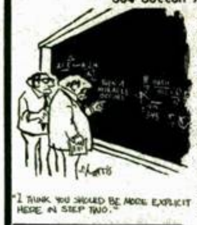
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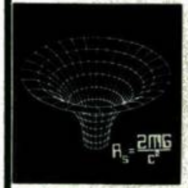
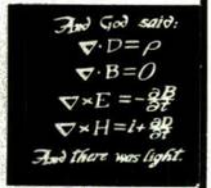
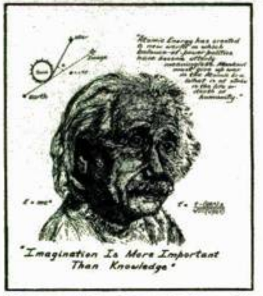
Front: Black hole with Schwarzschild's radius.
Back: Maxwell's equations of light. Printed on red, gold, lt.blue or black.
Style No. 100-05




And God said:
$\nabla \cdot D = \rho$
$\nabla \cdot B = 0$
$\nabla \times E = -\frac{\partial B}{\partial t}$
$\nabla \times H = i + \frac{\partial D}{\partial t}$
And there was light.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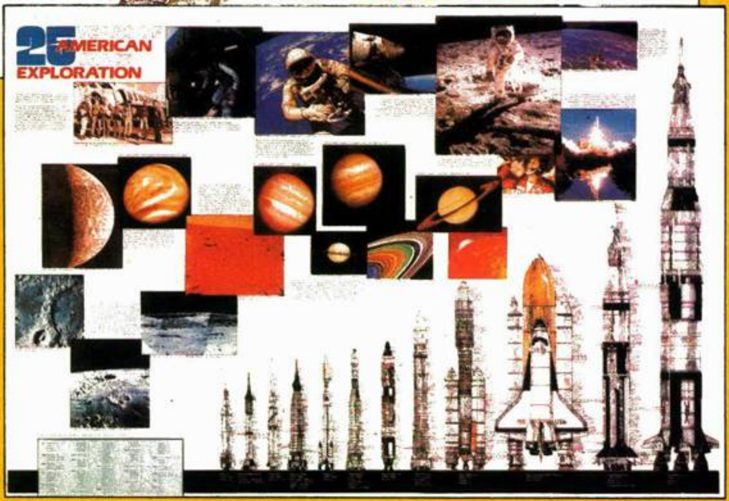

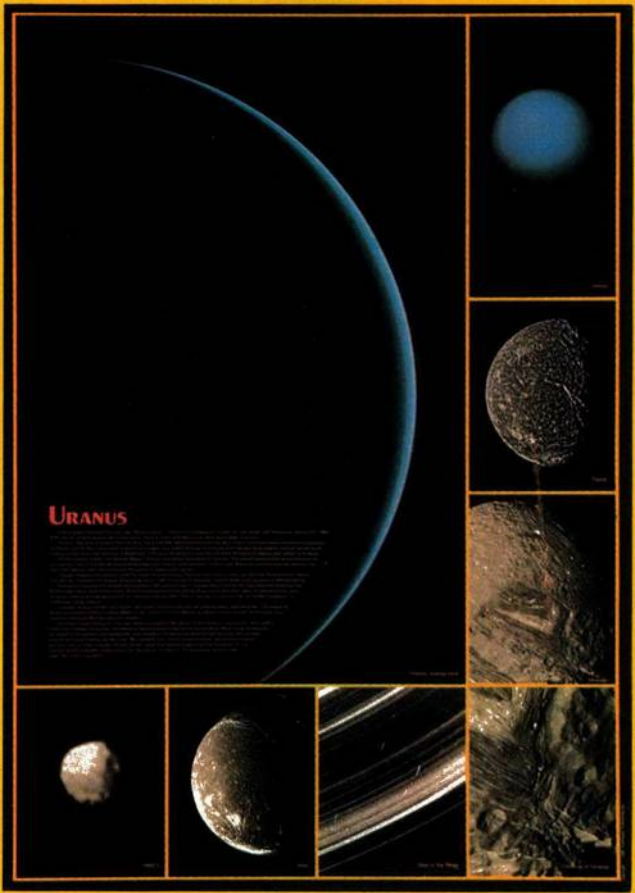

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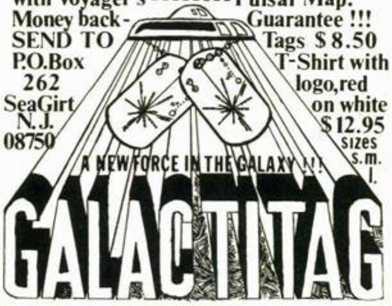
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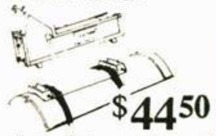

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WANTED — Help and ideas writing a newsletter that would cover all aspects of astronomy at the local level. Also want correspondence with clubs that would be willing to receive the newsletter. Contact Gary Anderson, 8191 Woodland Shore, Lot #12, Brighton, MI 48116.

WANTED — Articles on Space Shuttle missions, especially Christa McAuliffe and Mission 51L, on all crew members of 51L, accounts of shuttle launches by witnesses, photos, postcards. Contact Pam S. Wetzel, 503 2nd Avenue, Altoona, PA 16602.

WANTED — Source of table of distances of twenty nearest star systems to the Sun and to one another. Must be accurate to at least one decimal place. Contact Sanford Meschkow, 126 Colfax Road, Havertown, PA 19083.

WANTED — Large Newtonian or Dobsonian telescope (24" to 30") to install in astronomy club observatory, which is 12 feet in diameter. Will pay a reasonable price. Contact Herman Stanley, Henry Co. Astronomy Club, Route 4 Garden Circle South, LaGrange, KY 40031. Phone (502) 845-2949.

WANTED — Correspondence with other amateur astronomers. I'm 23 years old and would especially like to hear from people 18-25 years of age. Contact Donna McLerran, 907 South Morris Street, Gainesville, TX 76240.

FOR SALE — 32mm wide-angle Erfle eyepiece, 2'' barrel, $75 (list $149.95). Novak Supershort 2'' Newtonian focuser with 1-1/4'' insert $25 (list $44.95). Nikkormat body, like new, with case $125. Shipping extra. Contact John Ramser, 3016 Belmont Drive, Roswell, NM 88201. Phone (505) 624-1784.

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WANTED — Information on a group or individuals interested in astronomy in the Quad City area of Iowa-Illinois. Contact T. L. Dufek, 3505 Jersey Ridge Road #721, Davenport, IA 52807.

WANTED — Accutrak automatic star tracker attachment for Accutrak system. Contact Joe Fedeli, 3291 Holme Avenue, Philadelphia, PA 19114. Phone (215) 952-5414.

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WANTED — 13.1" Dobsonian from Coulter Optical Co. or similar. Contact Dan Douglas, 4026 Shelley Avenue, Colorado Springs, CO 80910. Phone (303) 570-6806.

WANTED — New members Goddard Astronomical Society, Holliston, MA (20 miles west of Boston). Contact Harold Frohlich, 82 Anne Marie Drive, Holliston, MA 01746. Phone (617) 429-4820 or (617) 429-6942.

WANTED — Correspondence with anyone interested in astronomy and other sciences — would especially like to hear from those outside U.S. Contact Regina Mitchell, 540 South Franklin Street, Holbrook, MA 02343.

WANTED — 17-year-old high school senior desires correspondence with professional astronomers. Any information regarding how to become a professional astronomer is appreciated. Contact Aileen Yingst, 1807 Wilderness Trail, Berrien Springs, MI 49103.

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WANTED — Readers of ASTRONOMY to join observing project. Would like people participating to send observing reports in order to form a picture of the sky as it looks around the world. Contact W. R. Chadburn, 14 Oakdale Road, North Anston, Sheffield, South Yorkshire, S31 7EY, England.

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WANTED — Back issues of *Telescope Making*, especially #20, #23, and #24. Contact Richard Livitski, 12646 Kalnor Ave., Norwalk, CA 90650. Phone (213) 929-2376 (business phone, leave message).

WANTED — Jaegers 6" f/5 lens. Contact Erik Hansen, 786 Nordy 900 West #102, Salt Lake City, UT 84116. Phone (801) 359-9074.

WANTED — Quantum 8 or Questar 7. Describe condition, also accessories included and state price, negotiable. Contact L. Appel, 21945 Oakmont Ln., Brookfield, WI 53005. Phone (414) 782-3588 after 5 p.m.

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WANTED — Copy of *Outer Space Photography for the Amateur* by Henry Paul. Contact Russell Williams, 10630 Flaxon Street, Culver City, CA 90230. Phone (213) 837-8994.

WANTED — 5" or 6" Jaeger's refractor lens in good condition. Contact Michael Dudley, Route #1 Box 384C, Newport, PA 17074. Phone (717) 567-3235.

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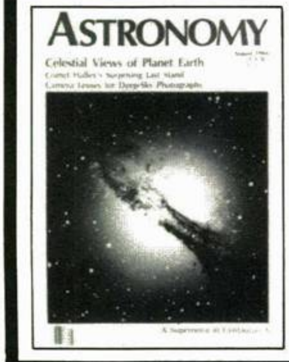

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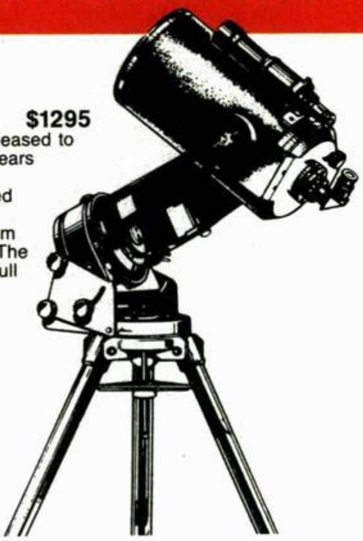

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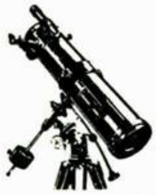

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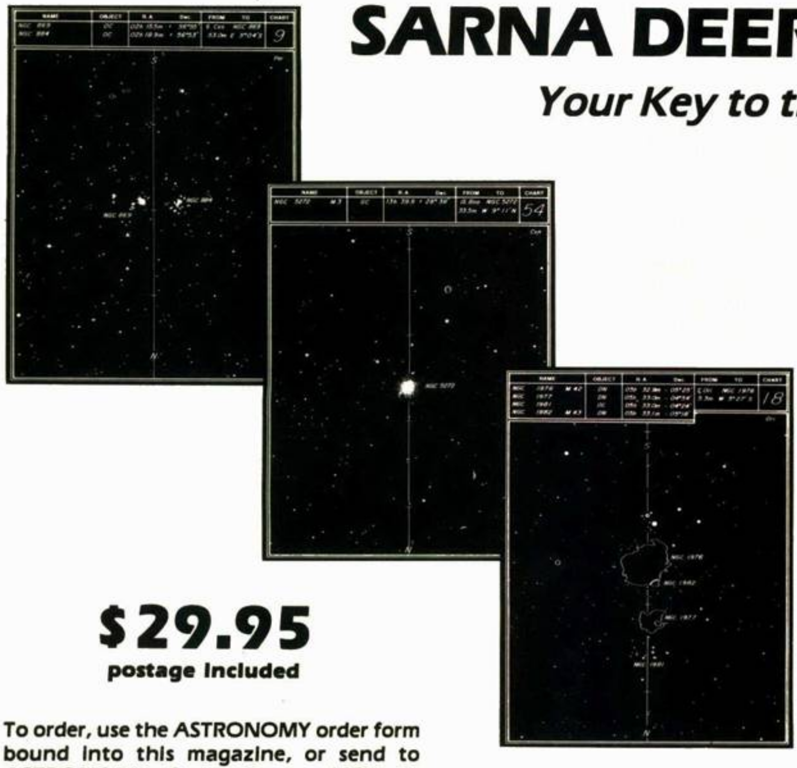

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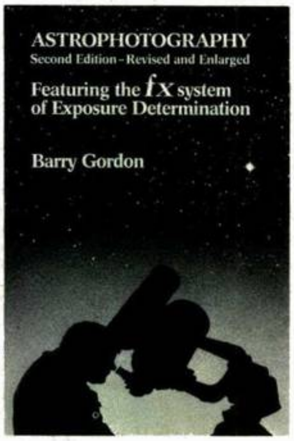
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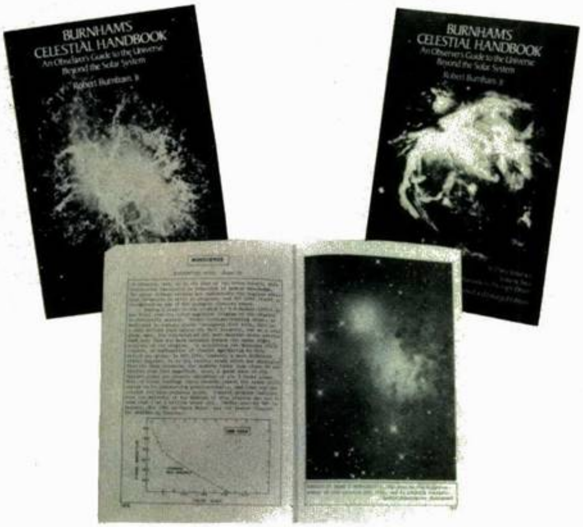
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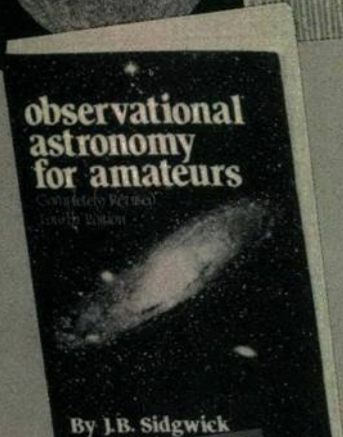
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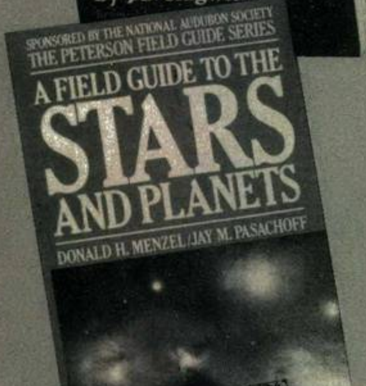
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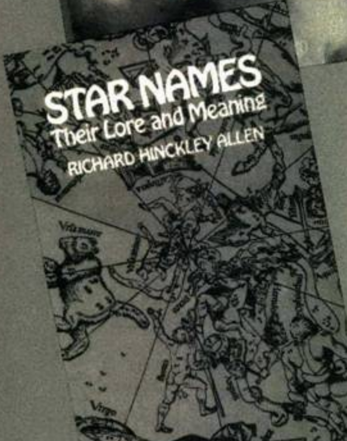
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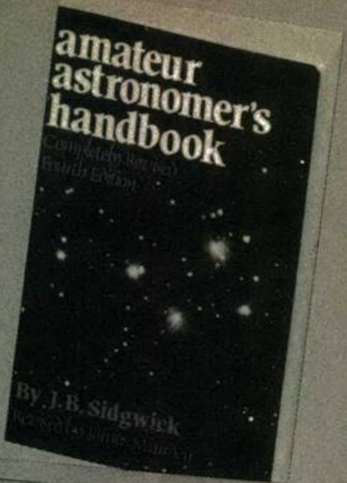
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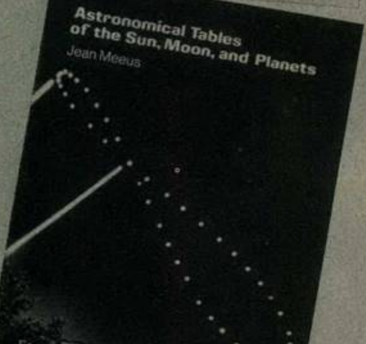
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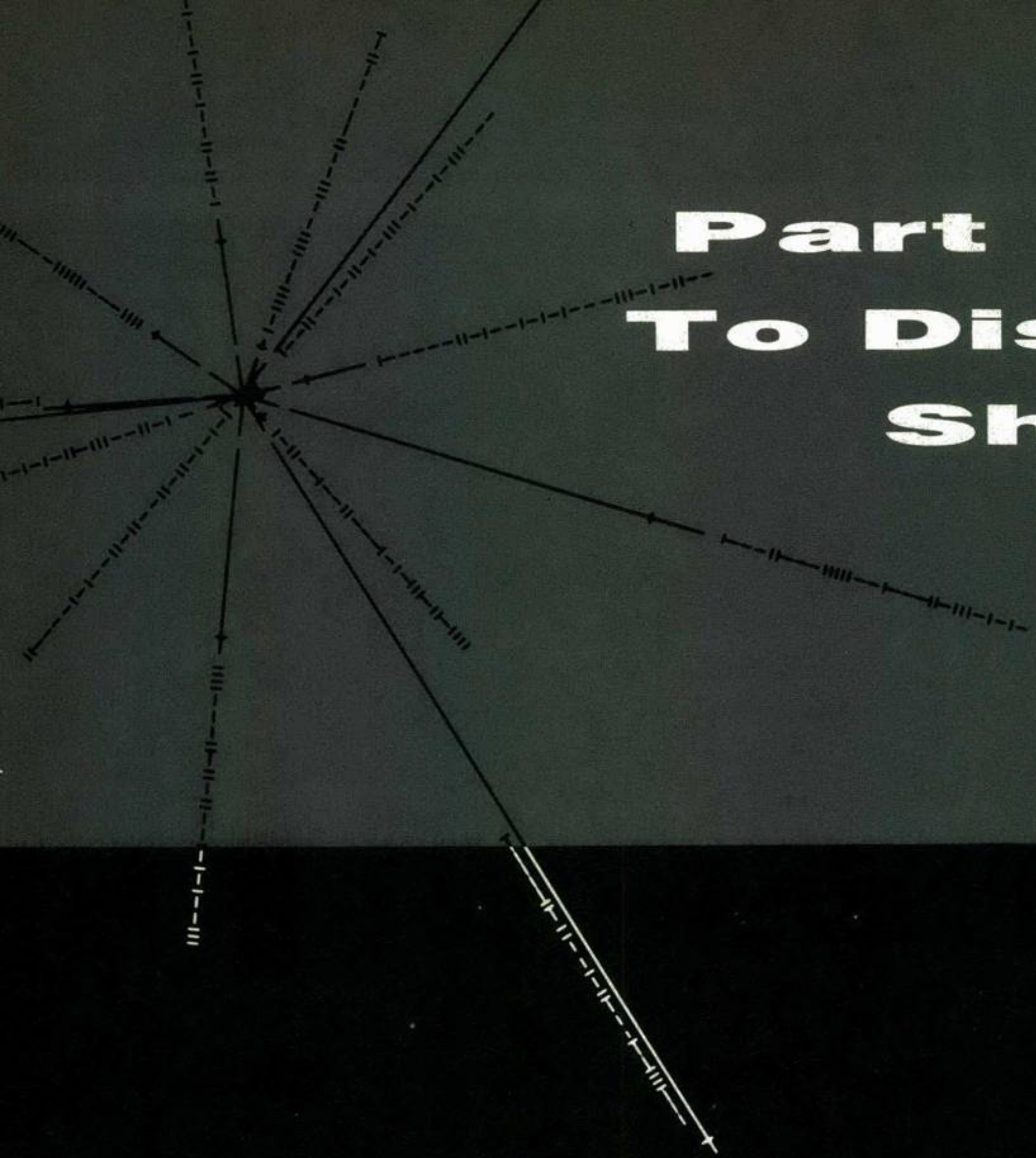


Part Two: To Distant Shores

Is talking about interstellar space flight realistic in the 1980s? After all, less than three decades have passed since humankind first put a spacecraft, Sputnik 1, into orbit. Some of you may even recall the first human-powered flight made by Orville Wright at Kitty Hawk in 1903.

We are still space rookies, beginners at firsthand exploration beyond our own atmosphere. Yet we are also, in a sense, already bound for the stars with robot probes — Pioneers 10 and 11 and Voyagers 1 and 2. Accelerated by the powerful gravity of Jupiter, these spacecraft have already escaped or will soon escape from the solar system. Their cruising speed will be about 9 kilometers per second, and at that rate it will take tens of thousands of years before they make a remote flyby of a nearby star. Nevertheless, they are our first efforts at interstellar flight.

Can we go farther and become true explorers of the stars? If so, what propulsion methods might we use? What are some of the problems we shall face?

Rockets and Propulsion

Hurl a rock into the air and you will see it arcs its way back to the ground. Throw it faster and it will fight gravity a bit longer and travel higher before returning to *terra firma*. However, if you throw the rock fast enough — a bit in excess of 40,000 kilometers per hour — you will never see it again.

Long ago Jules Verne envisaged shooting a spacecraft out of a great cannon in *From the Earth to the Moon*. This technique would certainly get projectiles into space, but it would also crush them (or their passengers) into useless blobs. The only practical method for launching spacecraft is a rocket. And the only practical type of rocket we have found so far is the chemical rocket. Like any other type of rocket, chemical rockets work by Newton's third law of motion, which states that every action has an equal and opposite reaction. Chemical rockets burn either solid or liquid fuel and an oxidizer at an exceedingly high temperature in a combustion chamber. The hot exhaust gases escaping behind the rocket propel it forward at high speed.

One of the most important properties of rocket propulsion is thrust — the reaction force working on a rocket, which is equal to the exhaust velocity multiplied by the mass of material expelled over a given time. With chemical rockets the thrust is relatively high because the rate at which the exhaust gases escape is high. But, once in space, chemical rockets lose much of their appeal because they burn fuel at a prodigious rate.

As a result, any spacecraft powered by chemical propulsion must reserve a large fraction of its initial mass for fuel, and even then the rocket engine uses fuel so quickly it only provides thrust for a relatively short time.

Chemical rockets will probably be used for all rocket launches and landings in the forseeable future. They may even continue to be used for maneuvering in space and for short-range Shuttle missions well into the next century. But for interstellar travel chemical-propulsion rockets are woefully inadequate: other technologies must be brought into play.

A Formula for Success

Today's fastest spacecraft move at a snail's pace when you consider the great distances between stars. Pioneer 10, for instance, will have a final speed of about 32,000 kilometers per hour. At that rate the craft would take 140,000 years to reach the nearest star, if it were heading in the right direction. This

STAR TREK

BY DAVID DARLING

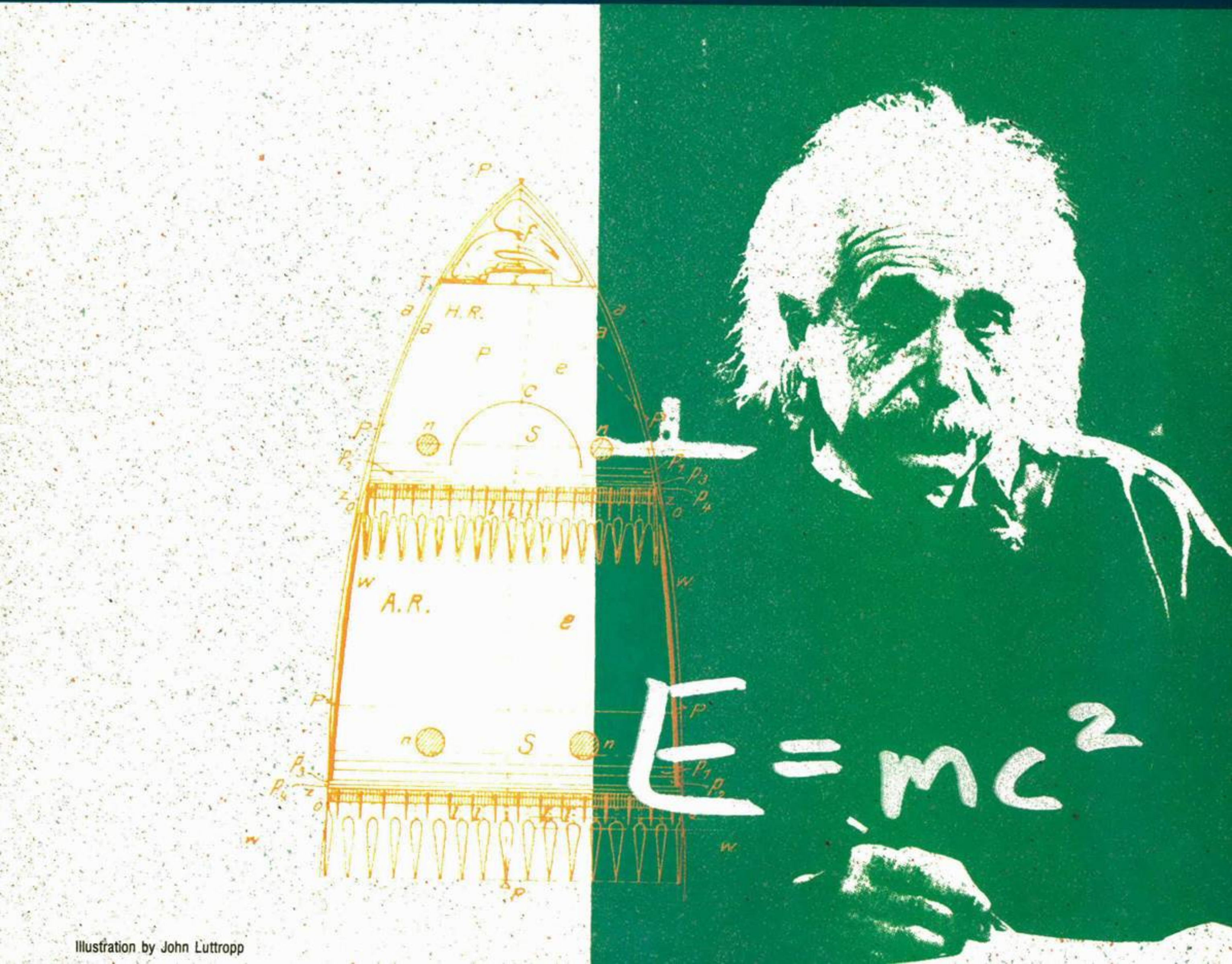


Illustration by John Luttropp

Increase a spacecraft's velocity to three-quarters that of light-speed, and the relativistic effects become plain. Now ship-time runs only two-thirds as fast as time does on Earth. Viewed by an observer at rest, the spaceship shrinks along its direction of motion by one-third and has one and one-half times its rest mass.

This clearly introduces new possibilities: if time slows down for astronauts on board a very fast-moving rocket, then the prospects for voyages to the stars — both nearby and remote — suddenly look much rosier.

isn't encouraging. But a simple formula allows us to see how much this situation can be improved:

$$v_f = v_e \log_e(m_i/m_f)$$

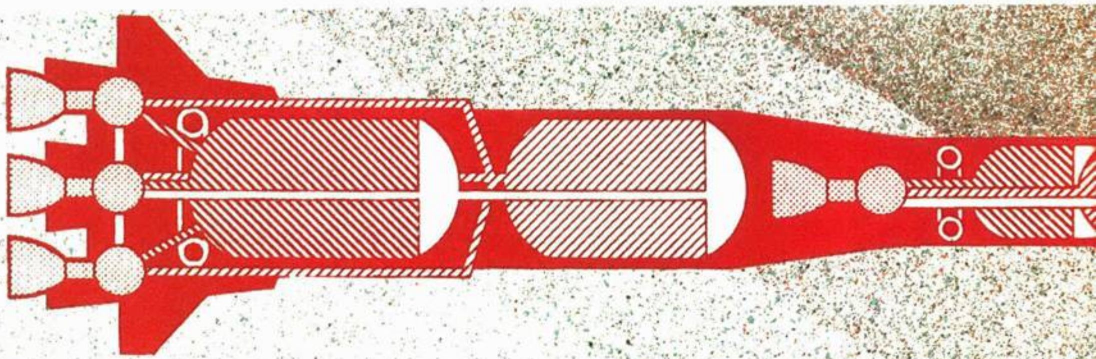
where v_f is a rocket's final velocity, v_e its exhaust velocity, m_i its initial mass, and m_f its final mass.

Chemical rockets can manage an exhaust speed of about 4 kilometers per second. To reach a final speed of 8 kilometers per second, the mass ratio (m_i/m_f) must be 7.4. To reach 16 kilometers per second, the mass ratio must be 55. And so the ratio goes, the problem getting worse as the final speed increases.

One way to cut back the mass ratio, which would enable a bigger payload with the same amount of fuel, is to use a staged rocket. Each stage can then be jettisoned after it is used. This loss of mass helps, but not nearly enough to allow practical star travel by chemical rocket engines.

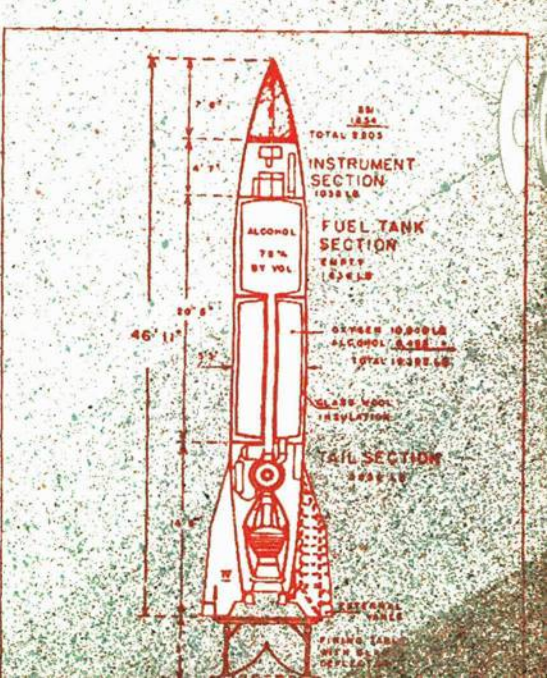
Rocket systems based on nuclear fission reactors or ion drives have already been tested. The idea behind a fission rocket is pumping a fluid like liquid hydrogen from a fuel tank through the core of a nuclear reactor. This fluid is then converted into a very hot gas that is expelled, thrusting the rocket. The resulting speed, though, is not nearly great enough for a starship.

The ion rocket, in comparison, spurts out a stream of charged particles like cesium ions after first accelerating the particles in an electric field provided by a fission reactor. However, the exhaust speed — only about 50 kilometers per second — is



$$\frac{V}{V_1} = \text{Lgnat}\left\{1+\frac{M_2}{M_1}\right\}$$

$$v_f = v_e \log_e(m_i/m_f)$$



insufficient for star flight. Someday ion rockets with exhaust speeds of up to 1,000 kilometers per second might be developed, but even these rockets wouldn't eliminate all problems. Reaching 10 percent of the speed of light — a desirable speed for interstellar flight — would still require an impossibly high mass ratio of 10 trillion to 1.

So how can a spacecraft attain one-tenth light-speed with a reasonably low mass ratio? One way might be using a fusion rocket. This would work along the same lines as the fusion reactors being developed today — by imprisoning a super-hot plasma of hydrogen long enough for it to "fuse" and become helium. (Fusion is the opposite of fission. It involves melding together lightweight atomic nuclei and the subsequent release of huge amounts of energy.) But triggering fusion reactions requires raising the temperature of the hydrogen plasma to over 100 million Kelvins. This is a tricky problem, which may or may not be solvable in the future.

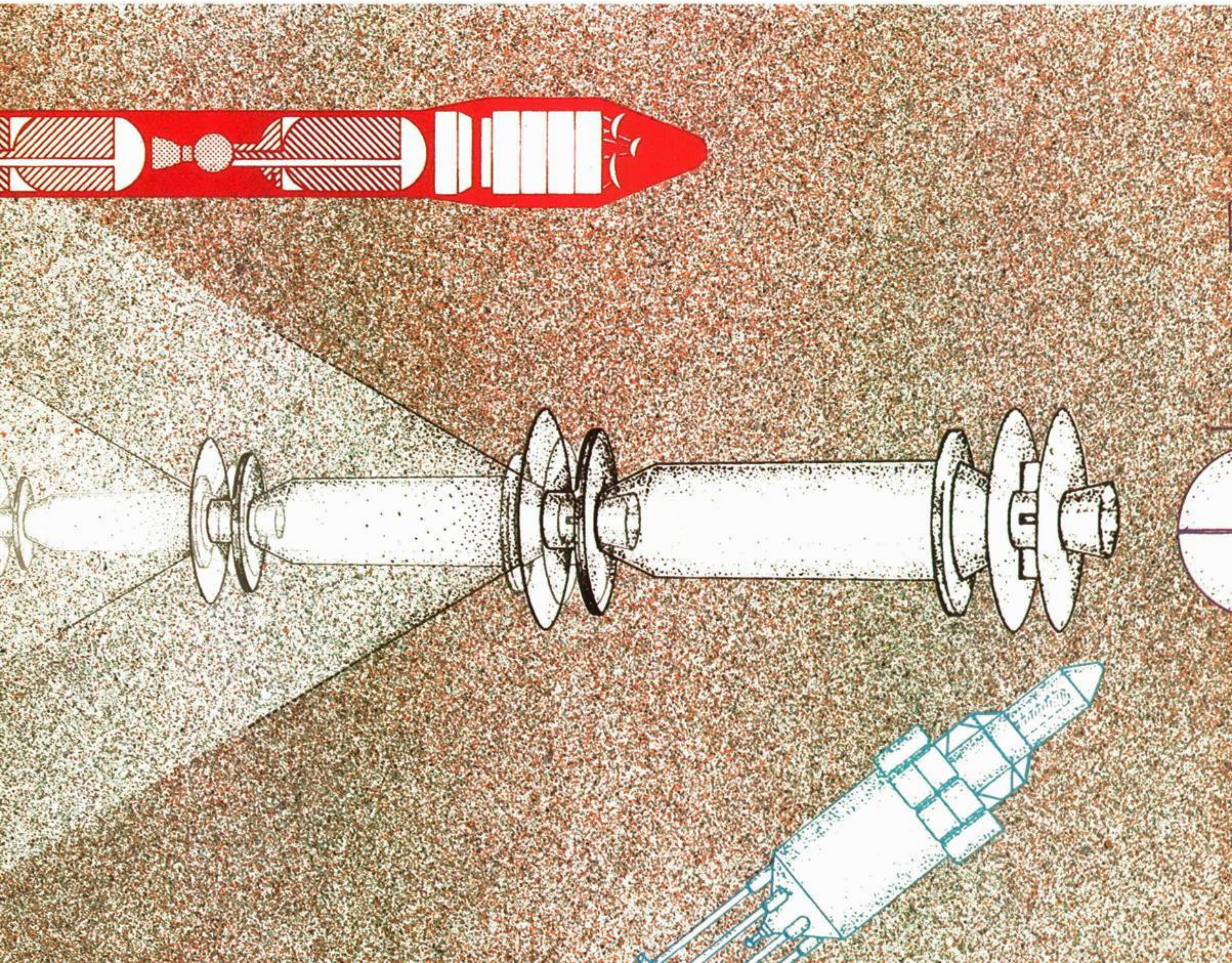
The exhaust speed of a fusion rocket could be as high as 10,000 kilometers per second, and accelerating up to 10 percent of light-speed would require a mass ratio of 20. So far so good. But what about slowing down at the other end of a flight? Because the fuel needed to slow the rocket must be accelerated to the velocity of the spacecraft, the mass ratio must be squared to 400. And if you want to come back to Earth again? Well, square the mass ratio again — to 160,000 — which means you would have to start out with 80 tons of propellant for each pound of payload you bring back from such a mission.

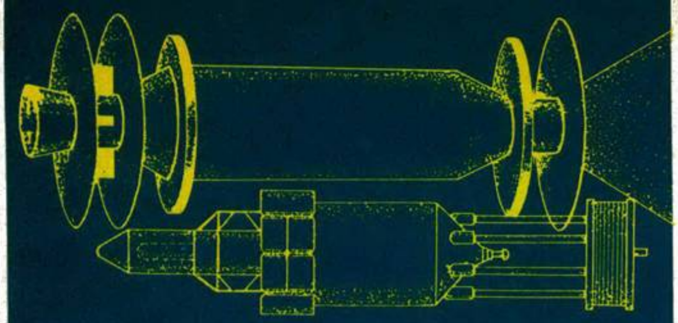
A variation on the basic fusion theme is the nuclear-pulse rocket, which forms the basis for Project Daedalus, a spaceship design proposed by the British Interplanetary Society. A nuclear-pulse rocket would work by firing pellets of frozen deuterium and helium^3 or some other such fuel into a reaction chamber. Bombarded by high-energy electrons or laser light, the pellet mixture would then fuse, giving the spacecraft a forward push. A 1978 plan for Daedalus proposed that 250 pellets be exploded each second, which would accelerate the spacecraft, over several years, to a final cruising speed of 36,000 kilometers per second (or 12 percent of light-speed). As a result, Daedalus would reach its proposed target — Barnard's Star, 1.8 parsecs away — in roughly fifty years. The unmanned mission would not involve deceleration of the main ship on arrival and would have a mass ratio of only about 12 to 1.

Into Interstellar Overdrive

Plain and simple fusion reactions aren't the end of the matter, however, because Einsteinian relativity also enters the picture. Move fast enough, according to this theory, and time on board the spacecraft slows down dramatically relative to time on a slower moving object. Clocks on board fast-moving spaceships run slower than clocks back on Earth. But that's not all, because at such high speeds dimensions shrink, while masses increase.

Can this fantasy of relativistic physics be true? Absolutely. It has been proved conclusively, over and over, by experiments with fast-moving particles on Earth. There is little doubt relativistic mechanics would also apply to larger masses like spacecraft





After early attempts with a nuclear-pulse rocket, starship designers will doubtlessly look for something considerably faster. An intelligent option seems to be the interstellar ram-jet (ISR), a ship that would use the interstellar medium itself as a fuel source.

This scenario has no end. Imagine a stage at which the ISR is traveling so quickly that any distance inside the universe is attainable within months, days, or even hours. This could make advanced, long-range relativistic travel possible, but for the passengers it is a one-way trip. The crew members of an ISR could never venture home again. "Home," as they once knew it, would no longer exist.

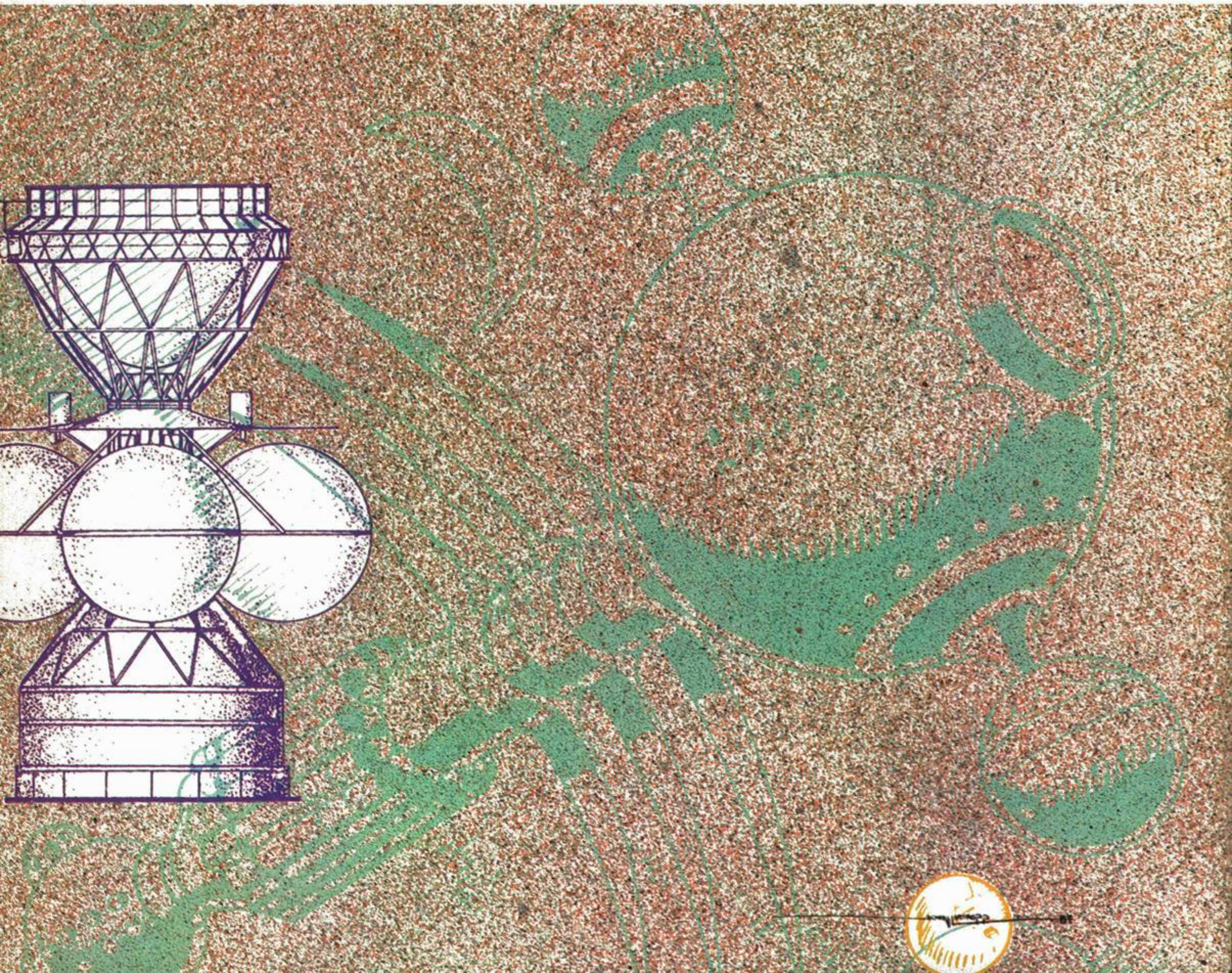
traveling at near light-speed.

The scale of these effects at very high speeds is dramatic. If the spacecraft moved at 10 percent of light-speed, little would change: clocks on board Daedalus, for example, would lose only 18 seconds per hour compared to stationary clocks. And the effect on the length and mass of the spacecraft would be equally small.

Increase a spacecraft's velocity to three-quarters that of light-speed, though, and the relativistic effects become plain. Now ship time runs only two-thirds as fast as time does on Earth. Viewed by an observer at rest, the spaceship shrinks along its direction of motion by one-third and has one and one-half times its rest mass.

This clearly introduces new possibilities: if time slows down for astronauts on board a very fast-moving rocket, then the prospects for voyages to the stars — both nearby and remote — suddenly look much rosier. Traveling steadily at nine-tenths the speed of light (270,000 kilometers per second) and ignoring the obvious need for periods of acceleration and deceleration, the crew could reach Proxima Centauri in just twenty-three months of ship-time. Including a reasonable survey period of say, eighteen months, implies a total mission duration of just over five years as experienced by the crew. Back on Earth, however, eleven years would have elapsed. The returning star travelers would be dismayed by how much their friends and families had aged.

On longer journeys and at higher speeds the situation is even



more dramatic. A 5.3-parsec round trip to Sirius at 99.9 percent light-speed would consume only nine months of an astronaut's life. But coming back to their home world, members of the Sirius crew would find that seventeen years had passed. Their children would have become middle-aged.

Over seventeen years technology and society may change, though perhaps not drastically. But imagine what could happen if a manned mission went to the center of our galaxy — 10,000 parsecs away — and back at 99.9 percent light-speed. The journey, according to the astronauts, would take a little under three thousand years. On Earth, meanwhile, 65,000 years would have elapsed!

Imagine a starship that could accelerate indefinitely at 1-g — the "acceleration due to gravity" on Earth. After one year of this acceleration the spacecraft would be almost 0.2 parsec away from home, traveling at an appreciable fraction of the speed of light. Relativistic effects would play a major role in such a journey. After five years on board the ship, the craft would be 25 parsecs distant; after about seven years the craft would have cruised 200 parsecs of space and back on Earth some 650 years would have passed by. After twelve years on board the craft the distance covered would increase to 35,000 parsecs — the diameter of the entire Milky Way — and, as measured by earthbound clocks, more than 100,000 years would have elapsed. Mission controllers at Houston would long since have ceased to care.

The 1-g starship, or anything remotely like it, sounds like a pipe dream. But is it? Could we ever fully exploit the bizarre effects of relativity for long-range interstellar or even intergalactic travel?

A Ram-Jet to the Stars

After early attempts with a nuclear pulse rocket, starship designers will doubtlessly look for something considerably faster. An intelligent option seems to be the interstellar ram-jet (ISR).

In a paper published over a quarter of a century ago, R. W. Bussard outlined an idea for a spaceship that would use the interstellar medium itself as a fuel source. Employing a weblike "ramscoop," the ship would generate a powerful magnetic field stretching tens of thousands of kilometers ahead of its flight path. This magnetic field would pull in all of the hydrogen ions in its proximity, and these ions would then be used in a fusion reactor located at the heart of the ship.

Aside from the obvious technological problems in building an ISR, there is a question of efficiency. At low speeds the ramscoop would not be effective, so some other propulsion system like a nuclear pulse rocket would be needed to accelerate at a flight's beginning. The ramscoop would start at higher speeds, achieving something like 50 percent of peak thrust at 6,000 kilometers per second. By Bussard's estimate, the ISR could achieve the "ideal sustained 1-g acceleration" if it varied the intake of its scoop from 10,000 square kilometers in a high-ion density region of space to 10,000,000 square kilometers in a low-density region.

With the ISR the greater the speed, the better. As speed increases from the ship's perspective, the length between any two points in space — along the direction of motion — decreases. This is not what a stationary observer would see. Nevertheless, an onboard observer's point of view is just as valid. This means that as the ISR goes faster, it "sees" the hydrogen ions along its forward path packed closer and closer together. At 99.9 percent of the speed of light all of the ions in a 10,000-parsec column between Earth and the galactic center would appear squeezed inside a cylinder only 450 parsecs long!

There are fantastic possibilities for ISR travel. Picture the starship leaving the solar system under nuclear-pulse drive. After a few months the ramscoop takes over, drawing in small rations of hydrogen ions at first, but, as time goes on, gulping in more and more. The relativistic length compression brings more and more ions within range of the ramscoop, and the fusion engine is fed with an ever-growing supply of fuel. A countereffect is that the mass of the ISR must also increase — a penalty of relativistic travel — so part of the increased thrust is unavailable for gaining speed. As the ram-jet approaches the ultimate limit of the speed of light ever more closely, it is steered through the thickest parts of the interstellar medium by its crew. Then, a whisker away from light-speed itself, the ship heads out of the Galaxy. The intergalactic medium is much thinner but, seen from the hurtling ram-jet, it appears dense and continues to supply the craft with ample fuel.

This scenario has no end. Imagine a stage at which the ISR is traveling so quickly that any distance inside the universe is attainable within months, days, or even hours. This could make advanced, long-range, relativistic travel possible, but for the passengers it is a one-way trip. The crew members of an ISR could never venture home again. "Home," as they once knew it, would no longer exist.

Any Time, Any Place . . .

We have already passed into the realm of science fiction: The ram-jet is a spacecraft that may not exist for centuries, if it ever exists at all. Dare we go further?

One last, wild speculation is perhaps worthwhile, if only for the sheer fun of it: sending a spacecraft into a black hole. Imagine that the craft was built to withstand the colossal tidal forces acting upon it in and around such an object. Then possibly — just possibly — the craft could reenter the universe at a different point in time and space. Of course this is an outlandish suggestion: we're not sure black holes even exist, let alone act as "wormholes" providing transport to other parts of the cosmos.

But let's suppose. What if black holes act as cosmic tunnels? A key problem facing all long-range relativistic travelers could be overcome. A black hole would offer the past, so that after exploring some distant star system the crew of a relativistic spacecraft could plummet into a convenient black hole and reappear close to home at a time shortly after it left!

The most suitable black holes for this kind of space-time hopping are the supermassive ones, those that probably inhabit the cores of many galaxies, including perhaps the Milky Way. Big black holes, it turns out, would subject a spacecraft and its crew to far lesser tidal forces than, say, star-sized black holes. Imagine that in the remote future a multimillion-solar-mass black hole at our galaxy's core could become the Grand Central Station for all long-haul star journeys. End of wild speculation!

Colonizing the Stars

Humans will undoubtedly move outward into space, first colonizing some nearby worlds: a permanent base with observatories, mining operations, and a hotel on the Moon; a smaller base on Mars; maybe a scientific outpost on Ganymede, followed by others on distant Titan and Triton.

And then the stars. After the Daedalus-like probes have finished their early survey work, a manned mission may head for 61 Cygni, Tau (τ) Ceti, or Sigma (σ) Pavonis — all promising targets within 6 parsecs of Earth. Then, with ISR technology mastered, we may move on, spreading inside an ever-expanding bubble some tens and later hundreds of parsecs across.

As humans move out into the Galaxy, they will have to adapt to the conditions they find. New cultures, ethics, sciences, and arts could bloom, perhaps influenced by other intelligent species. *Homo sapiens* itself may branch out along new evolutionary lines, changing physically and intellectually to suit other, novel environments. And all of this may take place within a tiny piece of our Milky Way Galaxy, a disk-shaped collection of 200 billion stars and one of billions of galaxies in the universe. Even if humankind reaches this highly ambitious goal of colonizing nearby stars, our species' journey into space will have just begun.

David J. Darling is a computer scientist and freelance science writer living in England. The first part of "Star Trek" appeared in last month's Stellar Frontiers.

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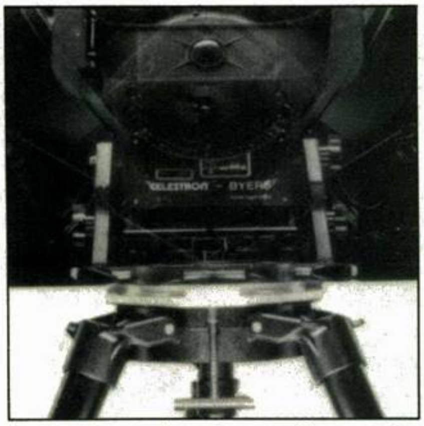

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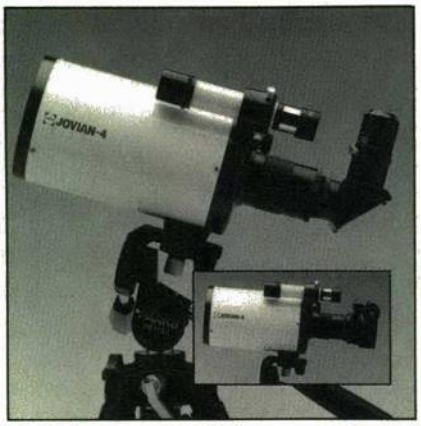

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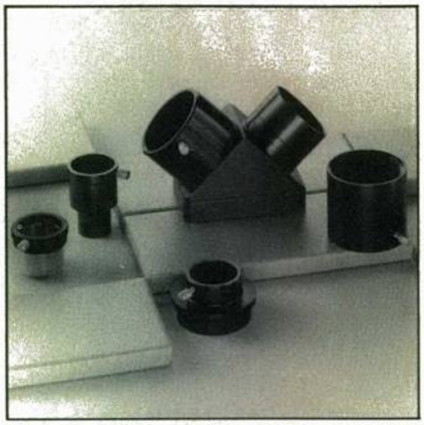

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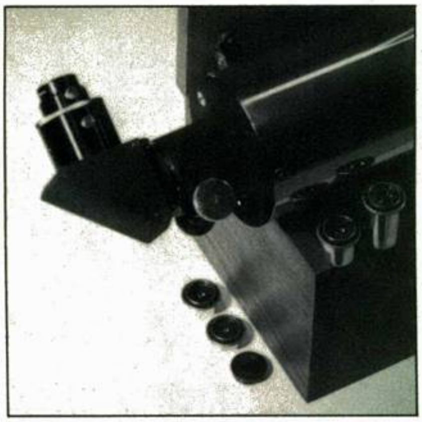

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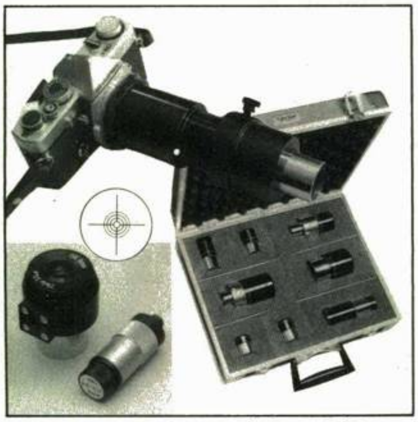

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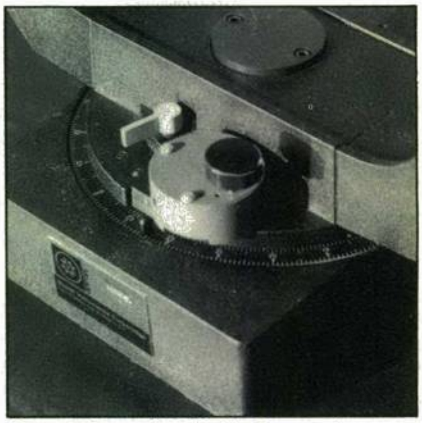

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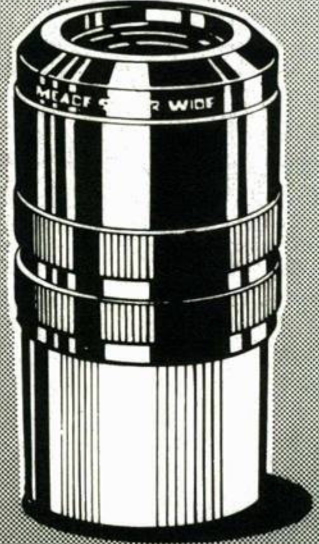

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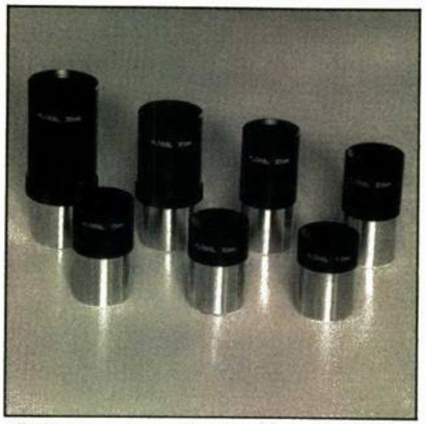

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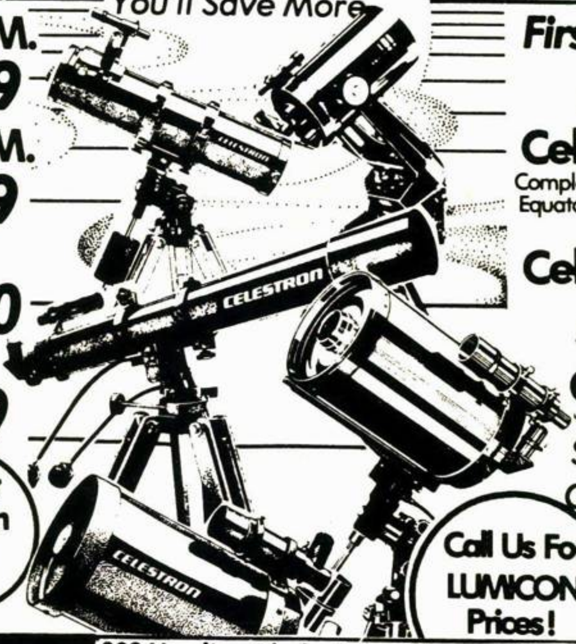

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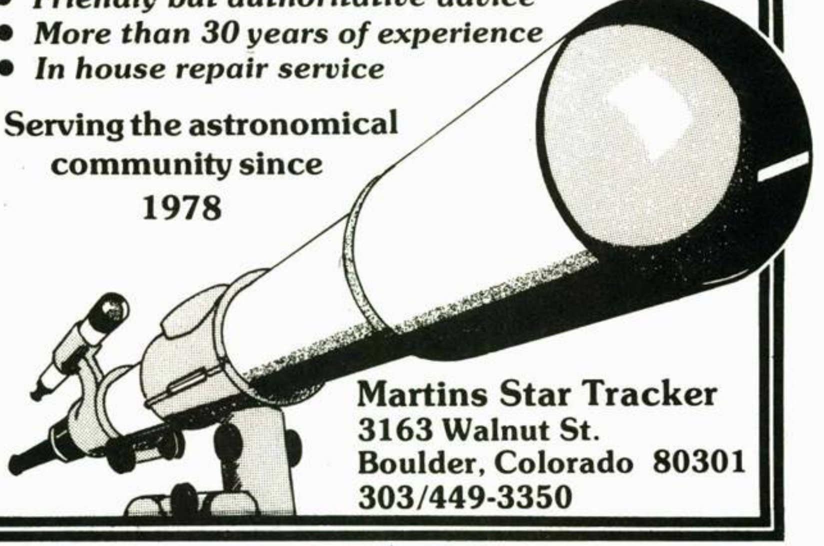

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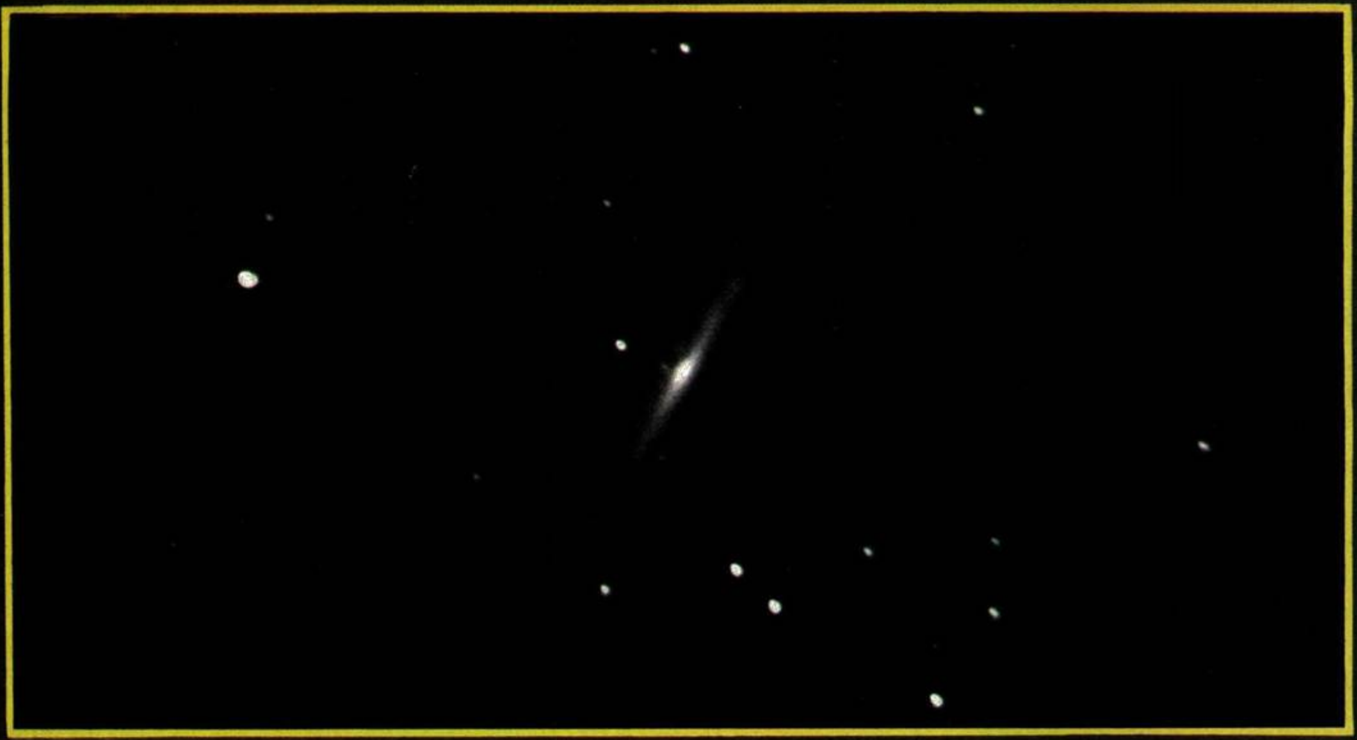
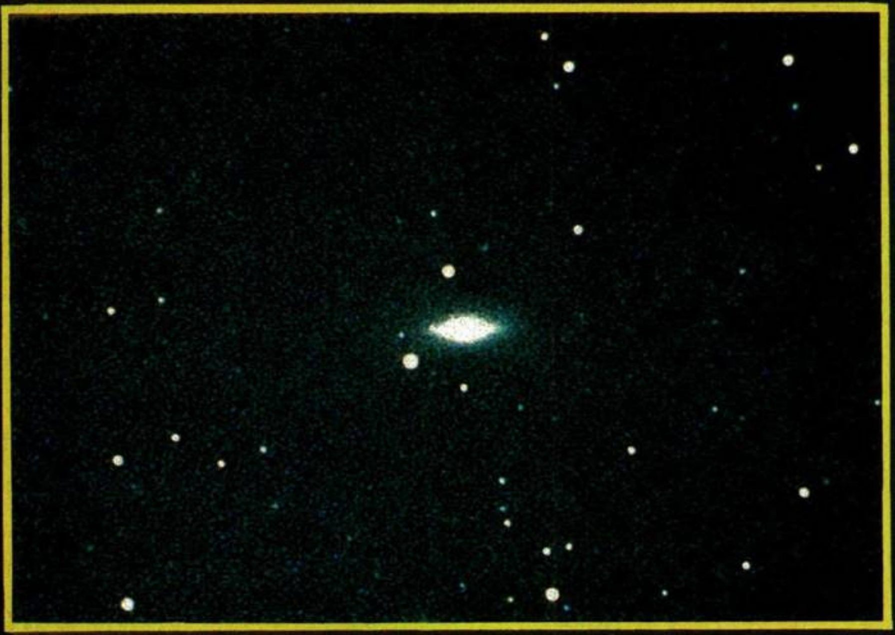


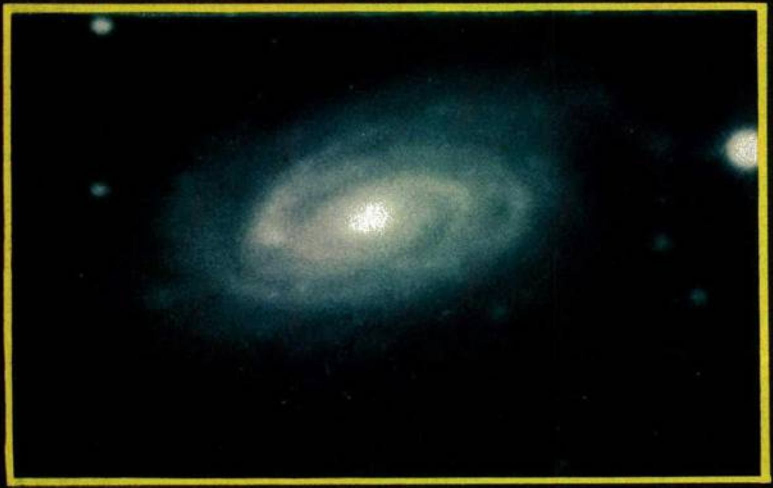


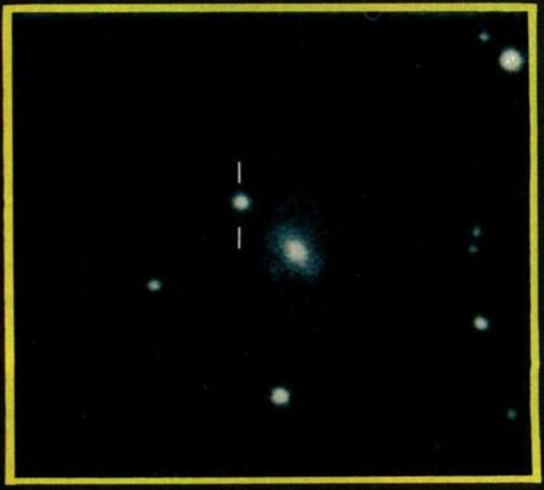
Above: The slender edge-on galaxy NGC-5907 is one of the finest examples of its class. In a 6-inch telescope NGC-5907 is visible as a silvery needle of light with a slight central bulge. Photo by Gene Brings.

Left: Although Charles Messier's confused notes leave its original identity open to question, M-102 is commonly thought to be the bright lenticular galaxy NGC-5866. Photo by Jack Newton.

Below left: The graceful spiral NGC-5985 is a superb target for backyard telescopes, offering a bright core and subtle spiral structure. Photo by K. Alexander Brownlee.

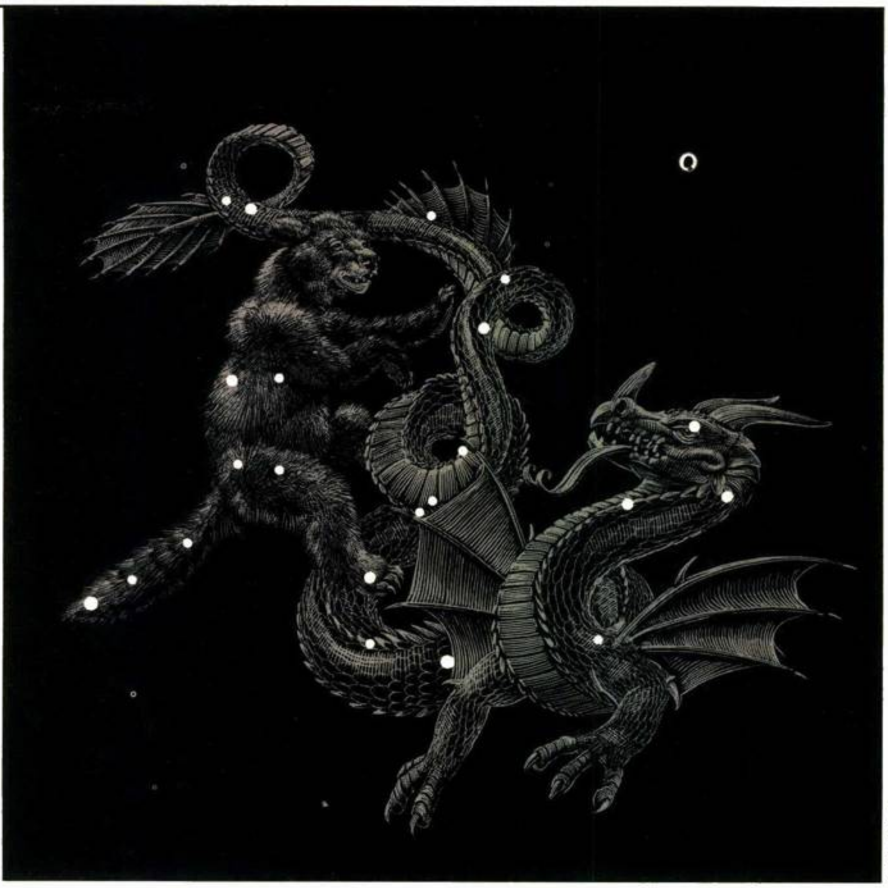
Below: Unimpressive in small telescopes, the spiral NGC-4319 nevertheless is a fascinating target: near its nucleus is the 15th-magnitude quasar Markarian 205. Both objects can be glimpsed in a single high-power field with a 14-inch telescope. Photo by Martin C. Germano.





Draco

Dra
Draconis



Keith Ward

A lengthy and sprawling constellation, **Draco** the Dragon winds its way through 1,083 square degrees of sky around the north celestial pole. This stretched constellation almost completely surrounds Ursa Minor and its Little Dipper asterism. Because it is so far from the plane of the Galaxy, Draco contains few galactic objects, but it is rich in galaxies visible in backyard telescopes.

The identification of one of the brightest deep-sky objects in Draco is embroiled in controversy. When Charles Messier published his description of **M-102** in the *Connaissance des Temps* in 1781, he identified the fuzzy object as "a very faint nebula situated between Omicron Bootis and Iota Draconis; near to it is a 6th-magnitude star." The problem with this description is that Omicron (ο) Bootis lies some 40° south of Iota (ι) Draconis, which suggests Messier did not mean to say what he published.

In the *Bedford Catalogue*, published in 1844, William H. Smyth suggested that Omicron Bootis was an obvious misprint for Theta (θ) Bootis, which lies in the right area. Between these stars lies a group of five galaxies including the bright objects NGC-5866 and NGC-5879. Here the matter becomes even more confused: Smyth reported observing NGC-5879 and described this object as the "brightest in the group." However, the brightest in the group is clearly NGC-5866. Confirming this line of reasoning, Harlow Shapley in 1917 identified M-102 with the nebulosity NGC-5866.

In 1947 astronomer Helen Sawyer Hogg revealed that Pierre Mechain, Messier's assistant who discovered M-101, had written to the German astronomer J. Bernoulli in 1786. Mechain claimed that Messier had made a clerical mistake and that M-102 was simply a repeated observation of Ursa Major's M-101. Despite this evidence directly from the pen of the discoverer, most astronomers continue to accept NGC-5866 as M-102, if for no other reason than as a tribute to the human limitations of science.

Its long and controversial history notwithstanding, M-102 is a bright, easy-to-find galaxy for users of small scopes. Located at the southern edge of Draco, 4° southwest of the bright star Iota Draconis, this object is one of the finest examples of a lenticular galaxy in the sky. Shining at magnitude 10.0 and spanning 5.2′ by 2.3′, M-102 is visible as a thin saucer-shaped blotch of nebulosity in large finder scopes. A 6-inch scope shows it as a bright oval nucleus centered in a large, elliptical halo of faint greenish-gray light.

Four more galaxies lie in close proximity. **NGC-5905** and **NGC-5908** form a pair of faint galaxies 2° due east of M-102. NGC-5905 is a barred spiral with a blue-light magnitude of 12.3 and dimensions of 4.2′ by 3.3′; NGC-5908 is a normal spiral dimly glowing at magnitude 11.9 with dimensions of only 3.2′ by 1.3′. Observers with 8- or 10-inch telescopes trained on the field containing these galaxies can expect to see two faint, fuzzy, slightly elongated patches of light separated by 12.5′. NGC-5905 is the one on the northwestern end, while NGC-5908 lies to the southeast of its larger neighbor. The galaxies' redshifts are nearly equal, but they're different enough to suggest the two objects aren't close neighbors in space.

One degree north of the pair is the large, beautiful galaxy **NGC-5907**, surpassed as an edge-on spiral only by NGC-4565 in Coma Berenices. NGC-5907 is an Sb-type spiral inclined almost exactly edge-on to our line of sight; its magnitude of 10.4 and dimensions of 12.3′ by 1.8′ make it easily visible in large binoculars or small telescopes. A 3-inch refractor at moderate power shows this galaxy as a uniformly bright sliver of silvery-white light with a slight central bulge measuring slightly over 1′ across. A 12-inch scope at high power shows a bright streak of grayish light with a 2′-long central bulge and a thin dark lane bisecting the galaxy's long axis. Larger telescopes show NGC-5907 as a brighter streak of light but don't significantly increase the amount of visible detail.

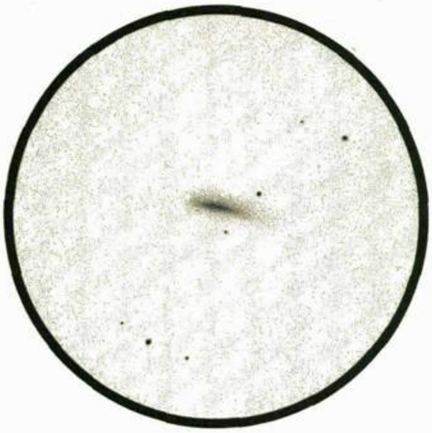
The little Sb-type spiral **NGC-5879**, one of those galaxies temporarily thought to be M-102, lies just 1° north-northwest of NGC-5907. This galaxy has a magnitude of 11.5, measures 4.4′ by 1.7′ across, and features a bright nucleus and faint spiral arms visible as an 11th-magnitude spot surrounded by a faint haze. Some 7′ north of the little galaxy is a 7th-magnitude star.

More bright galaxies lay scattered all across Draco. The fine Sb-type spiral **NGC-5985** is located 4.5° northeast of NGC-5879 in an area devoid of bright stars. This 11th-magnitude object is a mag-

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

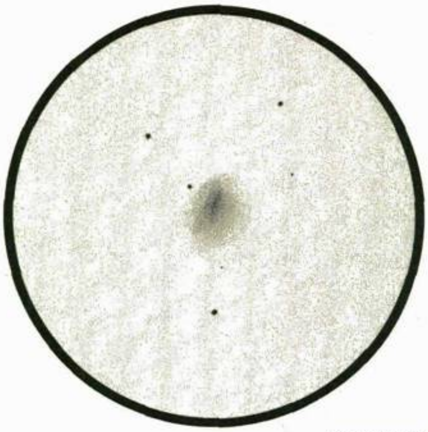
M-102

8-inch
f/10 SCT
100x



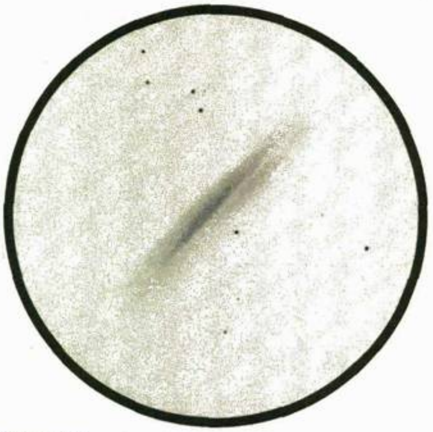
NGC-4319

17.5-inch
f/4.5 reflector
222x



NGC-5907

8-inch
f/10 SCT
100x



Sketches by David J. Eicher

nificent sight in large backyard telescopes: its small, oval central disk is wrapped in multiple, tightly-wound arms just visible in large scopes. Seven arcminutes west of this grand spiral is the diminutive elliptical galaxy **NGC-5982**, an 11th-magnitude fuzzy spot with a slight central brightening. Three-and-one-half degrees north-northeast of the 5982/5 pair is another worthwhile galaxy, **NGC-6015**. This galaxy shines at magnitude 11.2 and measures 5.4′ by 2.3′ in extent; its nucleus is bright and enveloped in a faint, grayish halo of faint nebulosity. It is a multiple-arm spiral, like NGC-5985, but its detail is somewhat more elusive.

The northeastern part of Draco contains two bright galaxies. **NGC-6503**, a magnitude 10.2 spiral, measures 6.2′ by 2.3′ across and is easily visible in small scopes as an elliptical smear of nebulosity. Ten-inch scopes show a typically bright nuclear region surrounded by a faint oval halo of misty light. Some 4′ east of this galaxy is a 9th-magnitude star. **NGC-6643** is an 11th-magnitude Sc-type spiral spanning only 3.9′ by 2.1′; it appears as a roundish patch of indistinct light in a 6-inch scope.

Lying nearly on top of the north pole of the ecliptic, between Delta (δ) and Zeta (ζ) Draconis, is the bright planetary nebula **NGC-6543**. This little nebula measures only 18″ across but shines at photographic magnitude 8.8, which means its nebulosity has an exceedingly high surface brightness (and can therefore withstand great magnification). This is fortunate because small telescope observers need to use high power on nights of steady seeing to distinguish the planetary's disk from bright stars in the area. NGC-6543 appears as a tiny, bluish-green spot of bright nebulosity in most telescopes; it takes a large scope at very high power to show the 11th-magnitude central star. (Small scopes have difficulty showing the star because it is overwhelmed by the bright nebulous disk.)

Four bright or unusual galaxies lie in the northwestern corner of Draco. **NGC-3735** is a fine Sb-type spiral shining at blue magnitude 12.2 and measuring 4.2′ by 1.0′. **NGC-4236** is an impressive object in small scopes, shining at magnitude 9.7 and measuring 18.6′ by 6.9′ across; it is a barred spiral and offers glimpses of mottled, knotty detail in its spiral arms to owners of large backyard scopes. **NGC-4256** is a blue, magnitude 12.4 Sb-type spiral resembling NGC-3735 and measuring 4.6′ by 1.0′ across.

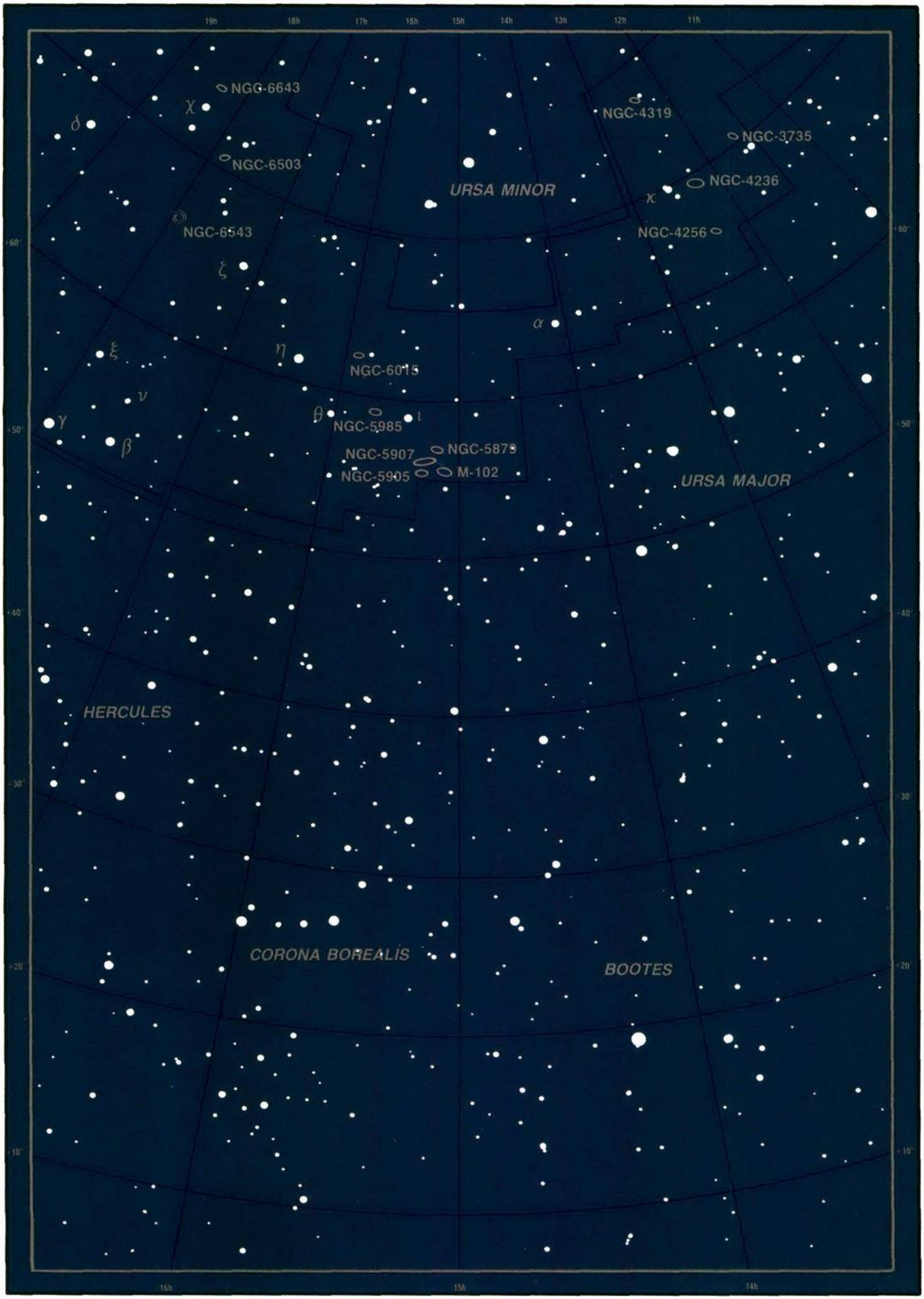
Our final galaxy, **NGC-4319**, offers an unusual surprise. The galaxy is a barred spiral dimly glowing at blue magnitude 12.2 and measuring 3.1′ by 2.5′ across — hardly unusual. But within its spiral arms is a magnitude 14.5 dot of light visible to owners of 16-inch or larger scopes; this dot is no star but **Markarian 205**, a quasar with a redshift that indicates a distance of 280 megaparsecs. The galaxy itself, measured by its redshift, is a mere 24 megaparsecs away, yet some astronomers claim the two objects are connected by faint nebulosity just visible on long-exposure CCD images. Are the dissident astronomers wrong, or will NGC-4319 and Markarian 205 disprove redshift measurements as indicators of cosmic distances?

Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
NGC-3735		§	11h 36.0m	+70°32′	12.2_B	4.2′x 1.0′	Sb
NGC-4236		§B	12h 16.7m	+69°28′	9.7	18.6′x 6.9′	SB⁺
NGC-4256		§	12h 18.7m	+65°54′	12.4_B	4.6′x 1.0′	Sb:
NGC-4319		§B	12h 21.7m	+75°19′	12.2_B	3.1′x 2.5′	SBb⁻
Mrk 205		QSO	12h 21.7m	+75°19′	14.5	stellar	
NGC-5866	M-102	§L	15h 06.5m	+55°46′	10.0	5.2′x 2.3′	SA0⁺ sp
NGC-5879		§	15h 09.8m	+57°00′	11.5	4.4′x 1.7′	Sb
NGC-5905		§B	15h 15.4m	+55°31′	12.3_B	4.2′x 3.3′	S(B)b
NGC-5907		§	15h 15.9m	+56°19′	10.4	12.3′x 1.8′	Sb⁺
NGC-5908		§	15h 16.7m	+55°25′	11.9	3.2′x 1.3′	Sb⁻
NGC-5985		§	15h 39.6m	+59°20′	11.0	5.5′x 3.2′	Sb
NGC-6015		§	15h 51.4m	+62°19′	11.2	5.4′x 2.3′	Sc
NGC-6503		§	17h 49.4m	+70°09′	10.2	6.2′x 2.3′	Sb
NGC-6543		■	17h 58.6m	+66°38′	8.8_P	18″	
NGC-6643		§	18h 19.8m	+74°34′	11.1	3.9′x 2.1′	Sc

■	*Planetary Nebula*
§	*Spiral Galaxy*
§B	*Barred Spiral Galaxy*
§L	*Lenticular Galaxy*
QSO	*Quasar*

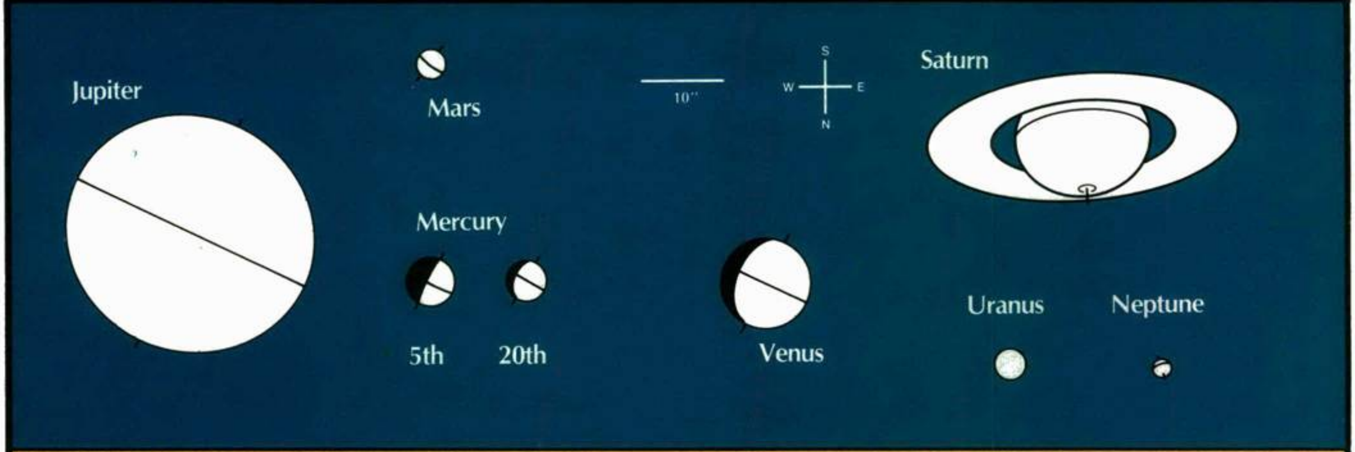
H = Hubble type for galaxies

Subscript "P" denotes photographic magnitude; subscript "B" denotes blue magnitude.

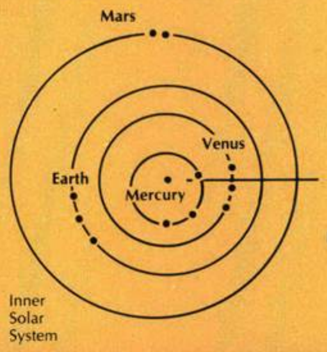

19h
18h
17h
16h
15h
14h
13h
12h
11h
NGC-6643
NGC-4319
NGC-3735
NGC-6503
NGC-4236
URSA MINOR
NGC-6543
NGC-4256
+60°
+50°
+40°
+30°
+20°
+10°
δ
χ
ζ
η
α
ξ
ν
γ
β
θ
ι
NGC-6015
NGC-5985
NGC-5907
NGC-5879
NGC-5905
M-102
URSA MAJOR
HERCULES
CORONA BOREALIS
BOOTES
16h
15h
14h

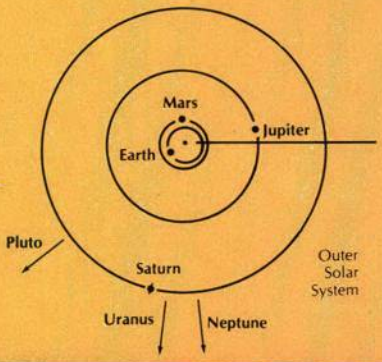
Planetary Data

April 1987


Jupiter
Mars
10''
S
W
E
N
Saturn
Mercury
5th
20th
Venus
Uranus
Neptune

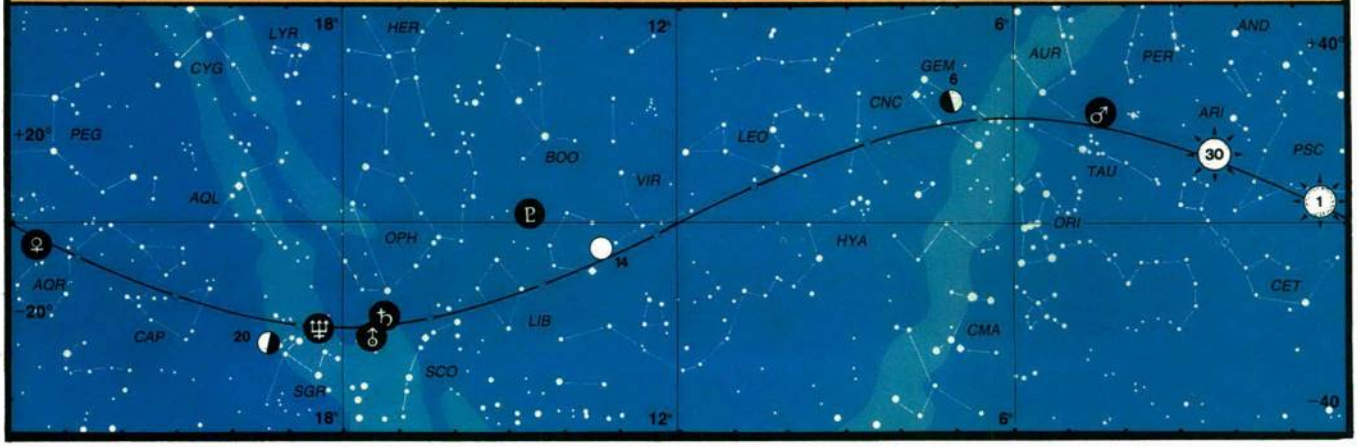
		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.7	32.1′	—	0.999	—	—	10°44.6′	0h 40.1m	4°19.2′
		15	−26.7	31.9′	—	1.003	—	—	24°30.5′	1h 31.4m	9°33.7′
		30	−26.7	31.8′	—	1.007	—	—	39°08.4′	2h 27.7m	14°35.9′
Mercury	☿	1	0.2	6.9″	59%	0.975	0.466	264°14.3′	343°48.2′	23h 03.1m	−8°13.3′
		15	−0.3	5.8″	77%	1.164	0.429	305°35.1′	3°36.0′	0h 17.2m	−0°53.0′
		30	−1.3	5.1″	95%	1.311	0.348	5°34.5′	30°53.4′	1h 56.8m	10°35.8′
Venus	♀	1	−4.0	13.7″	78%	1.214	0.727	278°39.6′	334°09.7′	22h 25.3m	−10°42.3′
		15	−4.0	12.8″	82%	1.302	0.728	300°47.8′	350°56.9′	23h 28.8m	−4°48.6′
		30	−3.9	12.0″	86%	1.390	0.728	324°31.6′	9°02.0′	0h 35.7m	−2°03.7′
Mars	♂	10	1.5	4.4″	95%	2.138	1.568	88°52.6′	63°03.8′	4h 03.4m	21°37.1′
		20	1.6	4.3″	96%	2.208	1.580	93°46.1′	69°43.5′	4h 31.7m	22°49.6′
Jupiter	♃	15	−2.0	33.3″	100%	5.921	4.955	7°34.5′	10°34.9′	0h 40.6m	3°11.0′
Saturn	♄	15	0.3	17.5″	100%	9.435	10.024	256°11.8′	261°09.7′	17h 22.0m	−21°32.9′
Uranus	♅	15	5.6	3.7″	100%	18.713	19.202	264°00.0′	266°39.8′	17h 46.1m	−23°32.6′
Neptune	♆	15	7.9	2.2″	100%	29.936	30.237	276°10.4′	278°04.0′	18h 35.3m	−22°09.3′
Pluto	♇	15	13.7	0.1″	100%	28.759	29.691	218°28.8′	219°07.8′	14h 48.3m	1°28.5′


Mars
Venus
Earth
Mercury
Inner
Solar
System


Mars
Jupiter
Earth
Pluto
Saturn
Uranus
Neptune
Outer
Solar
System

Moon Data

First Quarter. . . . . April 6 at 7h48m
Full Moon. . . . . April 14 at 2h31m
Last Quarter. . . . . April 20 at 22h15m
New Moon. . . . . April 28 at 1h34m
First Quarter. . . . . May 6 at 2h26m
Full Moon. . . . . May 13 at 12h50m
Apogee: April 6 at 6h38m. . . . . 404,319 km
Perigee: April 18 at 16h36m. . . 368,634 km


LYR
18h
HER
12h
6h
AND
+40°
CYG
GEM
6
AUR
PER
CNC
ARI
+20°
PEG
LEO
BOO
30
PSC
VIR
TAU
AQL
1
OPH
ORI
HYA
14
AQR
CET
−20°
LIB
CMA
CAP
20
SCO
SGR
18h
12h
6h
−40

Mercury

Mercury is visible in the morning sky during the first week of April, but its elevation is much too low for good telescopic viewing. Soon thereafter the tiny planet disappears into the morning twilight and remains out of sight until next month.

Venus

Venus continues to lose altitude this month though it is still easy to find because it is very bright. Venus displays a 13" disk that appears gibbous when viewed with medium- to high-power eyepieces. With seeing so unsteady near the horizon, locate the planet while it is low and follow it as it climbs higher in the brightening dawn.

On the morning of April 25, the Moon occults Venus for viewers in the eastern half of the country — a sight not to be missed. The disappearance will occur after sunrise for viewers northeast of a line from the Great Lakes region to the North Carolina seaboard and will occur before sunrise west of the line. In the south central states and western plains Venus will reappear from behind the Moon's dark limb before sunrise. In the West the event will be over by the time Venus and the Moon rise. To view the occultation, use a red photo filter with your telescope to darken the blue sky if necessary.

Mars

Mars is prominent in the evening sky, lying south of the Pleiades star cluster during the first few days of April. But in a telescope little is visible except at high magnifications because the planet's disk is only 4.3" across. Spring has just begun in Mars' northern hemisphere, which means that the Martian northern polar cap will begin shrinking. But you will find following this shrinking difficult because of Mars' great and steadily increasing distance.

Minor Planets

1 Ceres (magnitude 7.9) is in Sagittarius, several degrees to the northeast of the Lagoon and Trifid nebulae. Its positions:

1st: 18h 14m 19s, −21° 40.2′
10th: 18h 19m 52s, −21° 57.2′
20th: 18h 23m 54s, −22° 19.0′
30th: 18h 25m 25s, −22° 45.1′

Ceres rises around 1:30 a.m. local daylight time on the 15th.

2 Pallas (8.8) is retrograde in Hercules near Beta (β) and Gamma (γ) Herculis:

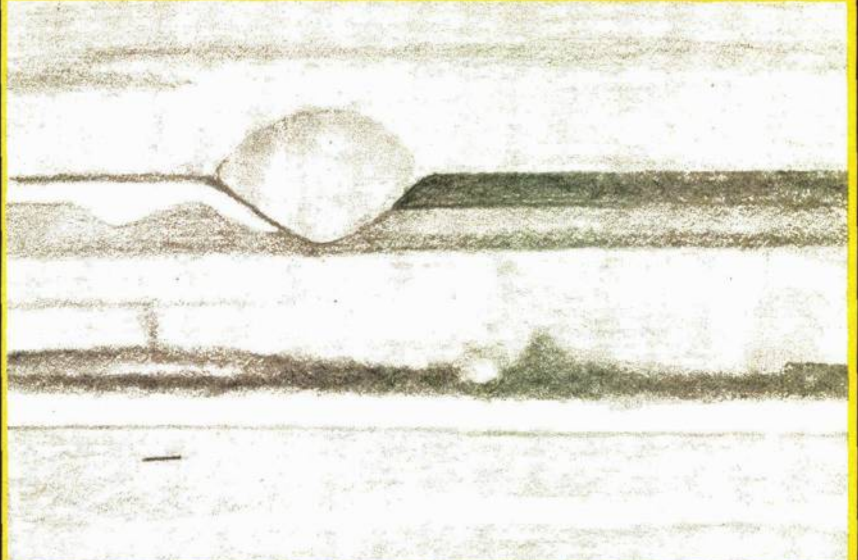
1st: 16h 25m 54s, 16° 21.1′
10th: 16h 24m 41s, 18° 41.3′
20th: 16h 20m 58s, 21° 07.0′
30th: 16h 15m 03s, 23° 13.6′

Pallas rises around 8:30 p.m. local daylight time on the 15th.

3 Juno (10.7) is in Aquarius, several degrees to the southwest of Beta (β) Aquarii. Its positions:

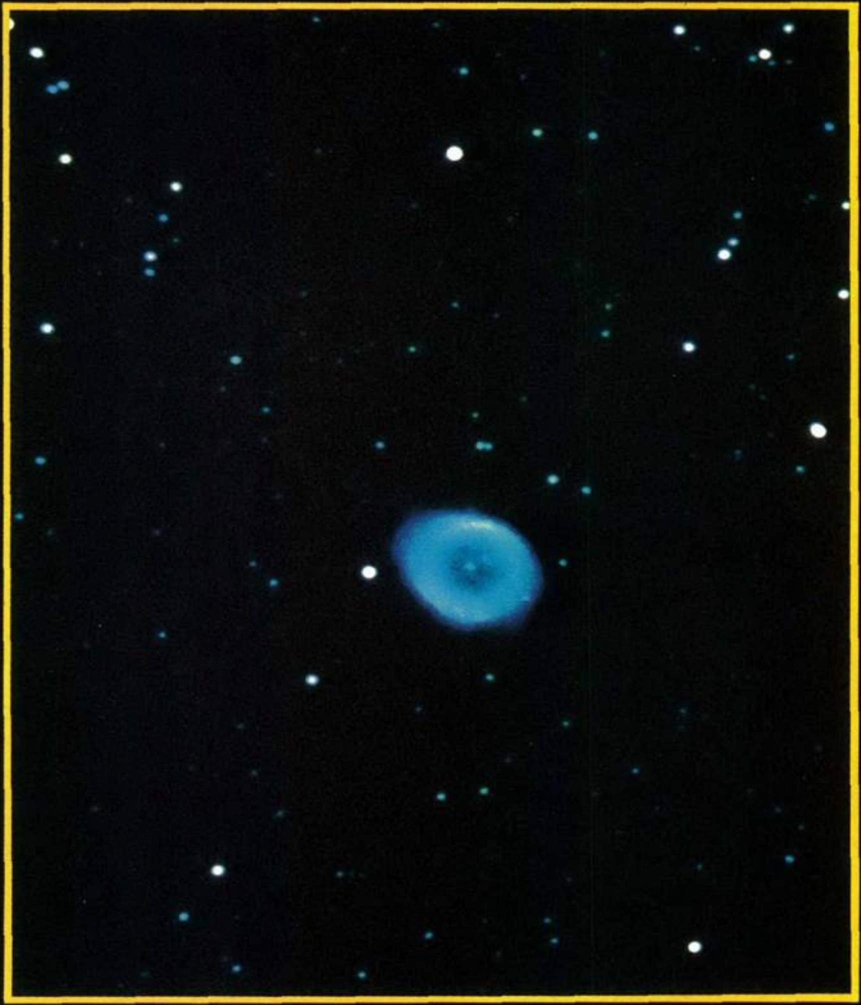
1st: 21h 01m 38s, −7° 37.4′
10th: 21h 13m 13s, −6° 40.6′
20th: 21h 25m 25s, −5° 36.4′
30th: 21h 36m 50s, −4° 32.6′

Juno rises about 4 a.m. local daylight time on the 15th.



This sketch of the area surrounding Jupiter's Great Red Spot shows fine detail in the giant planet's cloud bands. It is a composite rendition made using an 8-inch refractor at 165x, 203x, and 252x on November 9, 1986, during periods of excellent seeing. Sketch by Jim Phillips.

The 15th-magnitude central star belonging to the Ring Nebula in Lyra is one of the most elusive stars sought by backyard telescopists. It is plainly visible in this photograph, which also shows the strong bluish-green light characteristic of planetary nebulae. Photo by Bill Iburg, using a 14-inch SCT at f/9, Agfachrome 200 film chilled with a cold camera, and a 30-minute exposure.



4 Vesta (8.5) is too close to the Sun to be seen this month.

532 Herculina (9.4) is retrograding in Coma Berenices near the north galactic pole. Its positions:

1st: 13h 12m 28s, 22° 38.6′
10th: 13h 04m 48s, 23° 23.0′
20th: 12h 57m 12s, 23° 30.8′
30th: 12h 51m 16s, 23° 07.7′

At opposition on April 8, Herculina is visible all night long.

To locate a minor planet, plot its dated positions (given for 0h UT) lightly in pencil on a good star map (*Sky Atlas 2000.0*, for example) and sketch a smooth curve linking the points. Then observe the starfield at low magnification and photograph or plot by hand what you see. Check the field a night or two later; the "star" that moved is it. (All minor planet coordinates are for the epoch 2000.0.)

Jupiter

Jupiter passed conjunction with the Sun on March 27, but the planet won't become visible until late in April, when it will rise shortly before the Sun. This is still a little too early to recommence telescopic observations of Jupiter because the seeing will be terrible close to the horizon. You'll do better waiting until the planet is higher in the dawn sky next month.

Saturn

A distinctive object in the south-southwestern sky as dawn brightens, Saturn measures 17.5″ across on the 15th, while the rings spread 11″ farther on either side. The rings are tipping their northern surface 26.5° toward us, and the three main rings (A, B, and C, from the outer edge inward) are clearly visible in 6-inch telescopes with moderate magnification. If the inner C (or crepe) ring is hard to spot, look carefully for a dusky streak crossing the disk of Saturn itself, just below the middle of the planet.

Uranus

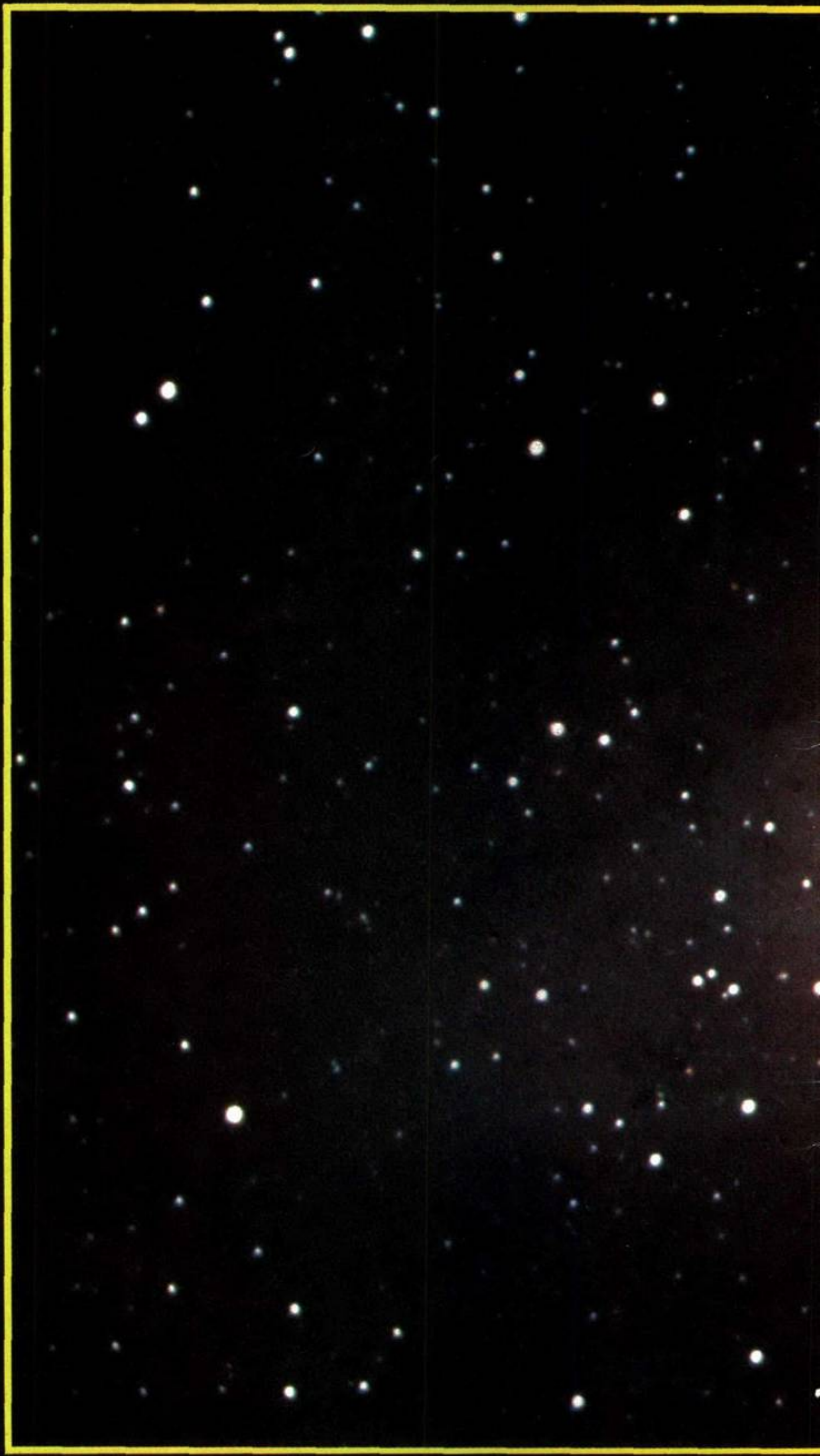
A finder chart for locating Uranus is on page 108 of the January 1987 issue. Uranus has a disk 3.7″ across; its brightness is magnitude 5.6. In your telescope's eyepiece it will have a strong greenish-blue color and a distinctively nonstellar disk.

Neptune

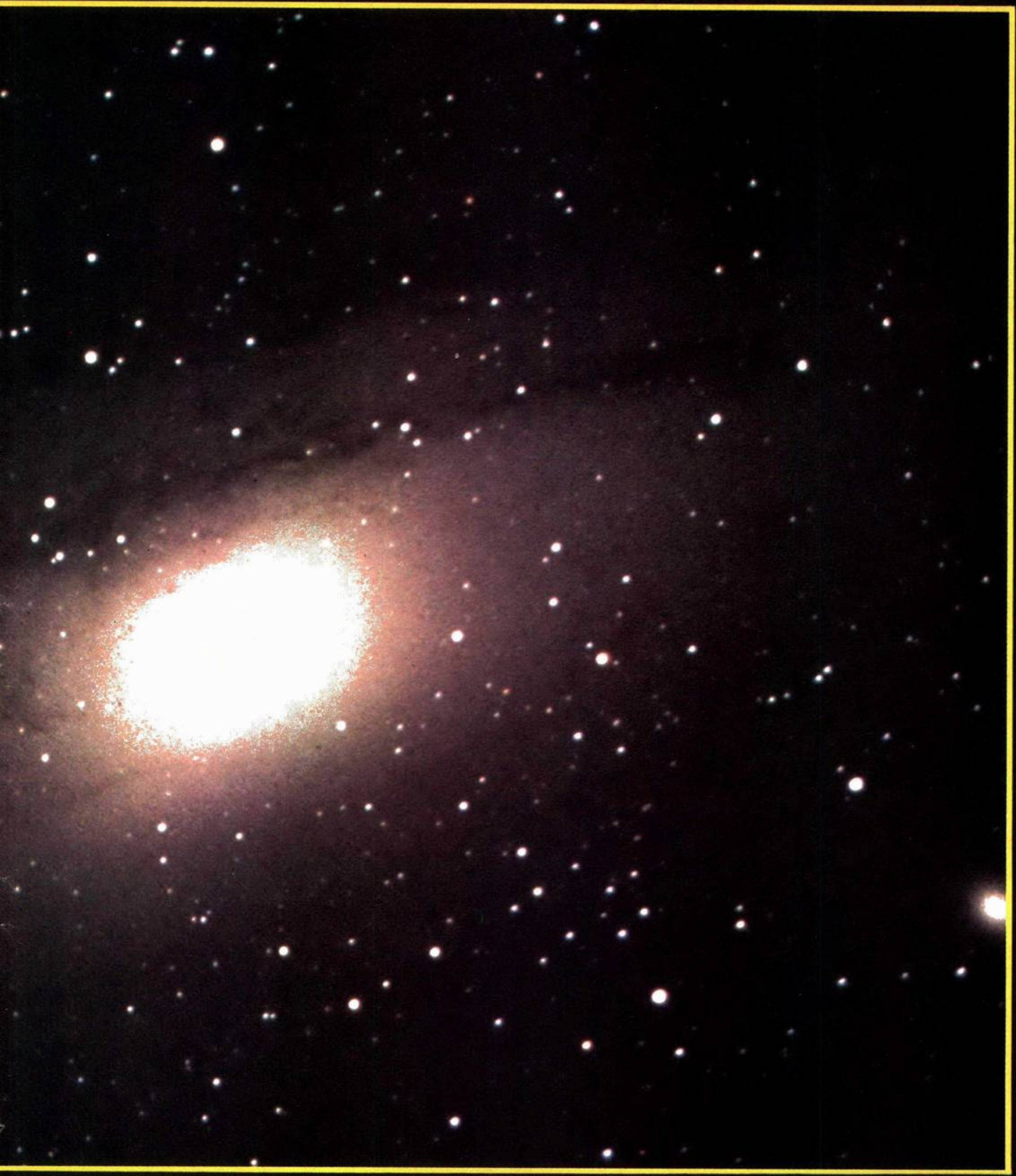
Neptune's finder chart is also on page 108 of the January 1987 issue. This month Neptune lies about a degree and a half north of M-22, a bright globular cluster to the northeast of Lambda (λ) Sagittarii, the star at the top of the Teapot asterism in Sagittarius. Neptune's disk is 2.2″ across and looks blue-gray; its brightness is magnitude 7.9.

Pluto

Reaching opposition on April 29, Pluto is at magnitude 13.7. This puts it beyond the reach of telescopes with less than about 8 inches' aperture, though in practice you may find a 10- or 12-incher necessary to locate Pluto. Use the finder chart on page 108 of the January 1987 issue and follow the same routine for finding a minor planet (see above).



Mike Mayerchak's impressive shot showing the core of the Andromeda Galaxy is this month's $100 "Best Astrophoto" winner. Mayerchak used a 14-inch SCT at f/5.5, 3M 1000 slide film, and a 50-minute exposure.



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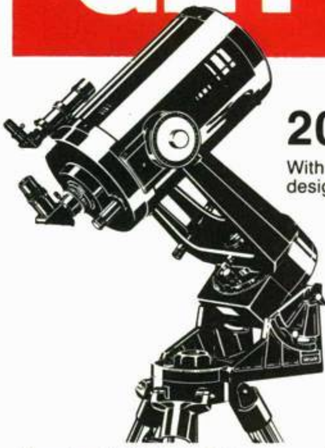

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